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Hospital management and healthcare policy: financing, resourcing and accessibility, volume II

Edited by
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Hospital management and healthcare policy: financing, resourcing and accessibility, volume II

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Table of contents

07 Editorial: Hospital management and healthcare policy: financing, resourcing and accessibility, volume II
Thomas T. H. Wan, Jay Shen and Hanadi Y. Hamadi

13 Analysis of the coupling coordination between traditional Chinese medicine medical services and economy and its influencing factors in China
Huan Liu, Zicheng Jiang, Jing Deng and Dexun Li

30 Practical quality improvement changes for a low-resourced pediatric unit
Phoebe H. Yager, Kevin Mary Callans, Aubrey Samost-Williams, Jose A. Bonilla, Luis J. G. Flores, Susana C. A. Hasbun, Angel E. A. Rodríguez, Alejandra B. A. Cárdenas, Alexia M. L. Núñez, Asitha D. L. Jayawardena, Evelyn J. Zablah and Christopher J. Hartnick

39 Will urban scale affect health services inequity? The empirical evidence from cities in China
Hongchuan Wang, Kaibo Xu, Handong Fang, Hui Lin and Huatang Zeng

49 The cross-regional settlement methods in hospitals and the treatment-seeking behavior of patients with malignant tumors in China: an evolutionary game model
Xinzhe Zhao, Linjin Li and Dan Zhang

66 Toripalimab plus chemotherapy in the treatment of metastatic triple-negative breast cancer: a cost-effectiveness analysis
Hongfu Cai, Lisheng Huang and Zhiwei Zheng

75 Point-of-care Testing HbA1c screening for type 2 diabetes in urban and rural areas of China: a cost-effectiveness analysis
Qing Shao, Xinglei Xie, Liu Wang, Lanyu Gao, Yuchen Hu and Yuwei Zhang

84 Drivers, adaptations, and public impacts of hospital closures: implications for policy
Soroush Saghafian

89 Relevant factors affecting nurse staffing: a qualitative study from the perspective of nursing managers
Gege Li, Waner Wang, Jiangfeng Pu, Zhanghao Xie, Yixuan Xu, Tiemei Shen and Huigen Huang

99 Spatial effects of township health centers' health resource allocation efficiency in China
Nannan Meng, Keyi Shen, Xinyue Zheng, Chengcheng Li, Xinhao Lin, Tong Pei, Dan Wu and Xuehui Meng

115 The efficiency evaluation of traditional Chinese medicine hospitals by data envelopment analysis in Zhengzhou, China
Jingjing Wang, Hui Lv, Hui Jiang and Wenjie Ren

123 Regional differences, dynamic evolution, and influencing factors of high-quality medical resources in China's ethnic minority areas
Binghua Liang, Lifeng Huang, Zhuo Chen, Bangyan Hao and Chengcheng Li

136 The impact of rural health insurance on vulnerability to chronic poverty among rural residents in China: analysis using Probit and IVprobit models
Min Zhang and Mu Wu

148 Can China's national comprehensive medical reform increase medical resources and reduce healthcare burden: evidence from Chinese provinces
Xiangyu Fu, Xiang Ren and Qirui Chen

162 Determinants of the low use of Thailand's Universal Coverage Scheme: a national cross-sectional study
Seung Chun Paek and Ning Jackie Zhang

173 Female and male treatable mortality: socioeconomic and public finance related factors across European countries
Aida Isabel Tavares

180 Reimagining hospital management: the balanced scorecard as a catalyst for employee retention and organizational excellence
Feng Guo, Ying Sophie Huang and Moeki Nemoto

186 A cost-reducing reimbursement programme? Effects of value-based reimbursement on healthcare costs
Thérèse Eriksson, Hans Tropp, Ann-Britt Wiréhn and Lars-Åke Levin

195 Healthcare provider perspectives on barriers and facilitators to integration of cardiovascular disease-related care into HIV care and treatment clinics in urban Tanzania
Theresia A. Ottaru, Fileuka C. Ngakongwa, Zeeshan Butt, Claudia A. Hawkins, Sylvia F. Kaaya, Emmy O. Metta, Pilly Chillo, Helen N. Siril, Lisa R. Hirschhorn and Gideon P. Kwesigabo

205 Preventable hospitalizations through ED: does the number of hospital beds matter under the global budget in a single-payer system in Taiwan?
Hsueh-Fen Chen, Hui-Min Hsieh and Wei-Shan Chang

215 An evaluation study of direct economic losses from surgical site infections in adults: structural equation modeling
Qiuxia Zuo, Di Liu, Baoji Dong, Yuan Zhou, Kexin Zhao and Ping Tian

225 Implementation and performance barriers in Iran's breast cancer screening program: a qualitative case study
Arezoo Jabbari, Zhila Najafpour, Sima Ourang, Somayeh Loveimi, Reyhane Bohrani and Mahsa Baymani

237 Health workers' motivation was significantly higher in private hospitals than public hospitals influenced by intrinsic and extrinsic factors in Northwest Ethiopia
Gebremariam Ayichew, Desta Debalkie Atnafu, Mohammed Hussein and Ayenew Takele Alemu

246 Data-driven segmentation of type 2 diabetes mellitus patients: an observational study on health care utilisation prior to an emergency department visit in Germany
Mirjam Rupprecht, Alessandro Campione, Yves Noel Wu, Antje Fischer-Rosinský, Anna Slagman, Dorothee Riedlinger, Martin Möckel, Thomas Keil, Lukas Reitzle and Cornelia Henschke

262 Will centralized drug procurement policy improve enterprises' total factor productivity?
Xin Li, Ran Tao, Wenxue Zou and Yuning Jin

277 Can the accepting foreign clinical data policy improve innovation investment of pharmaceutical firms? Empirical evidence from China
Mengjuan Jiang, Jingjing Huang, Su Wang, Yulu Fan and Yuwen Chen

293 Research on factors influencing the performance of public health governance in the ethnic areas of Sichuan Province: a study based on the TOE framework
Yuke Shi, Dandi Chen and Jing Zhou

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Editorial: Hospital management and healthcare policy: financing, resourcing and accessibility, volume II

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Editorial on the Research Topic
Hospital management and healthcare policy: financing, resourcing and accessibility, volume II

1 Introduction

As the editors of "FRONTIERS IN PUBLIC HEALTH," Research Topic—*Hospital management and healthcare policy: financing, resourcing and accessibility, volume 2*, we are pleased to introduce this Research Topic, which highlights pivotal research across multiple critical categories: Healthcare policy, Hospital Management, Healthcare Financing, Healthcare Information, and Health Insurance. Each of these domains represents a cornerstone in the architecture of effective public health systems worldwide. This Research Topic of studies provides invaluable insights into the challenges and innovations shaping the future of global health. This Research Topic brings together a diverse array of studies and analyses that collectively advance our understanding of strategies that could maximize and optimize healthcare organization performance and better outcomes. Each article offers its unique contributions to the ongoing discourse on how to improve public health systems globally. As we continue to face new challenges and opportunities in public health, the research presented here serves as a vital resource for governmental officials, policymakers, practitioners, and scholars dedicated to fostering healthier communities worldwide. Furthermore, the advancement of analytical tools or predictive analytics has shed light on the prospects for conducting value added evaluation of intervention strategies for global public health systems.

2 Synthesis of important findings of the 26 articles included in volume 2

2.1 Healthcare policies and reforms

Healthcare policy remains at the forefront of addressing disparities and optimizing care. The synthesis of seven studies across diverse health systems reveals how

governance mechanisms fundamentally shape system performance and resource allocation outcomes. Technology integration drives governance performance when combined with supportive organizational structures. Big data implementation in Sichuan Province's ethnic areas produced significant public health governance improvements only when paired with favorable ecological conditions and strengthened public opinion management. Technology alone generated limited impact, however. Effective governance required a synergistic integration of technological capabilities, organizational capacity, and environmental support systems. Payment reform fundamentally alters service delivery models across healthcare systems. Medical insurance payment reforms pushed hospitals away from traditional volume-based care toward value-driven service approaches. Fee-for-service models encouraged volume increases while bundled payments promoted efficiency improvements. Successful payment reforms require precise alignment between financial incentives and quality measures. China's National Comprehensive Medical Reform has demonstrated measurable outcomes across 31 provinces, increasing licensed physicians by 12.6% and reducing per capita inpatient costs by 7.2% in pilot regions. Regional integration requires context-specific implementation strategies rather than uniform national approaches. Urban and rural medical insurance integration across Chinese regions showed varying impact intensities depending on local characteristics. Single-tier payment models produced stronger effects than multi-tier systems. Policy impact followed an inverted U-shaped relationship with economic development levels and healthcare resource availability. Regions with moderate development levels achieved optimal integration outcomes. Pharmaceutical innovation policies create competitive pressures that stimulate research investment. China's acceptance of foreign clinical data increased R&D spending among domestic pharmaceutical firms by creating competitive pressures from imported drugs. Companies with stronger absorptive capacity benefited more from the policy. Non-state-owned firms engaged in new drug research showed greater innovation responses than state-owned enterprises. Traditional medicine integration faces economic dependencies that limit coordination development. Traditional Chinese medicine service levels exceeded economic development in most regions of China. Eastern regions achieved higher coordination than central, western, and northeastern areas. Economic development served as the decisive factor in traditional medicine's integration success. Hospital closure patterns reveal governance challenges at system levels. Six key drivers including financial pressures, demographic shifts, and policy changes created spillover effects that reduced quality at remaining facilities. Provider adaptations included reducing service duration rather than expanding capacity. These responses damaged patient outcomes while failing to address underlying capacity constraints. Policy implementation success requires multilevel approaches that address technological, organizational, and environmental factors simultaneously. Tailored implementation strategies based on local contexts show greater success rates than uniform national approaches. Future governance frameworks must account for institutional capacity, political support, and economic conditions that mediate policy transfer processes.

2.2 Hospital management and governance

Health management plays a pivotal role in ensuring the efficiency and effectiveness of healthcare delivery. Several important structural and ecological factors have been identified as drivers and critical factors to help optimize the performance of health delivery systems. For example, the German study on hospitalization of patients with type 2 diabetes reports that avoidable hospitalization can be realized if proper procedures for implementing disease management and utilization management strategies are being developed. An Ethiopian study has documented the intrinsic and extrinsic factors related to health workers are important motivating strategies for enhancing job satisfaction and quality of care. Similarly, a case study approach on nurse staffing has shed light on multidimensional optimization measures for establishing flexible and mobile nurse staffing. This could be an important quality management strategy for achieving optimal staffing and nursing care. In a study of operational efficiency of 16 traditional Chinese medicine hospitals in Zhengzhou, China, a power application of data envelop analysis (DEA) has demonstrated that a half of 16 hospitals were identified as having a lower level of efficiency measures. Thus, mechanisms and directions for improving efficiency are noted. Spatial effects of Chinese township health centers in rural areas are documented in a longitudinal study of health resource allocation. This report also highlights important governmental roles in making equitable resource allocations. Similarly, better quality improvement strategies are needed to reduce child mortality in middle and lower levels of resource countries. In summary, the cited six studies on health management and governance have suggested the path for optimizing the quality of care via improvement of technical and operational efficiency of healthcare organizations.

2.3 Healthcare financing, insurance, and cost effectiveness analysis

Health insurance is a fundamental pillar of universal health coverage. The appraisal of universal health insurance and maternal health services utilization before and after the implementation of Jaminan Kesehatan Nasional (JKN) in Indonesia provides critical insights into the impact of health insurance policies on healthcare access and outcomes. Another example of universal coverage is Thailand's Universal Coverage Scheme (UCS). Its experience shows that although 75% of the population are covered by UCS, many healthy young people, who have jobs with high income and reside in urban areas, do not enroll in or use UCS, mainly due to long waiting queues, inconvenient office hours, and quality of care of those healthcare facilities covered by UCS; those people often choose either private-providers or self-medication.

Health insurance and payment reforms have occurred in some countries in recent years, with varied degrees of success. Analyzing the China Household Tracking Survey (CFPS) data reveals that the implementation of the catastrophic insurance program significantly reduces financial burdens of healthcare for

both urban and rural residents, with rural residents, high-income groups, and non-older adult populations being benefited more, indicating that the urban-rural gap in financial burdens due to severe illnesses has been narrowed in China. A study examines the 2011–2019 data of 31 European Union countries reports that public finance management focusing on the identification of policy priorities is associated with the reduction of pre-mature mortalities for both men and women although mortality rates in both sexes vary cross different counties that have different mortality rates. Taiwan's experience in implementing global budget under a single-payer system shows associations between hospital beds per population and hospital admission through emergency department (ED) among patients with diabetes-related ambulatory care sensitive conditions (ACSC). The findings indicate that under hospital global budgeting with a floating-point value mechanism, more hospital beds likely motivate hospitals to admit ED patients with ACSCs, suggesting urgent needs to add value-based incentive mechanisms to the existing global budget program to encourage healthcare providers focusing on quality of care rather than volume generating. In fact, a Swedish study has reported positive effects of value-based reimbursement on healthcare cost, showing 11 percent decrease per episode of care (i.e., inpatient and outpatient care) among patients undergoing lumbar spine surgeries, resulting from better coordinated post-discharge care.

Several studies in China have also evaluated cost effectiveness of health services in such areas as disease screening, surgery infection, and cancer treatment. They provide empirical evidence of achieving cost-effectiveness in clinical practice. One study evaluates the point-of-care testing (POCT) glycosylated hemoglobin (HbA1c) screening for Type 2 diabetes in both urban and rural areas of China. Its findings indicate that POCT is more cost-effective than other testing options such as venous blood HbA1c and fasting capillary glucose (FCG), suggesting POCT could be recommended for future clinical practice in China. Another study, based on the 2023 and 2024 data of three tertiary hospitals in Xinjiang, found an average direct economic loss of $1,364 per patient with surgical site infections (SSI) or hospital acquired infections, as compared with their counterparts without any SSI, suggesting a reduction in SSI is likely to improve efficiency of inpatient care. The third study measures the cost-effectiveness of the interventions, quality-adjusted life-year (QALY), and incremental cost-effectiveness ratio (ICER), to compare tislelizumab plus chemotherapy vs. chemotherapy as first-line treatment for extensive-stage small cell lung cancer (ES-SCLC). It, combining the consideration of the wiliness to pay threshold, concludes that tislelizumab plus platinum and etoposide seems to be a cost-effective treatment option for ES-SCLC compared to the standard chemotherapy. The last study uses clinical trials' data to compares the cost-effectiveness of incorporating toripalimab alongside chemotherapy vs. the placebo + chemotherapy option, treating patients diagnosed with metastatic triple-negative breast cancer (mTNBC). The study, with the consideration of the willingness to pay threshold, that toripalimab plus chemotherapy is a more cost-effective strategy than the placebo + chemotherapy option.

3 Prospects for developing predictive analytics and innovative healthcare research

The authors of this Research Topic have made substantive contributions to both the theoretical and methodological advancement of healthcare research. Nonetheless, more systematic investigations are needed in health economics and implementation science, particularly through experimental study designs combined with longitudinal analyses of panel data.

The future of global health research depends on building collaborative teams and evaluating healthcare management strategies that improve both efficiency and effectiveness in service delivery.

3.1 Approaches

Risk identification and stratification are essential for delivering targeted health services. Demonstration projects should be designed to collect both personal and contextual information, enabling sustainable and cost-effective care models at the population level.

We recommend a two-stage analytic approach to study healthcare utilization and overutilization:

1. Stage 1: Automatic interaction detector (AID) analysis
    - Predictors: demographic, social, and contextual factors (*Xi*).
    - Outcome: demand for ambulatory care (*Y*).
    - Objective: to identify mutually exclusive, relatively homogenous subgroups of healthcare users.
2. Stage 2: Behavioral predictors
    - Predictors: motivation for lifestyle change, risk perceptions (*Zj*).
    - Outcome: use of residual variance of the outcome variable from Stage 1 as the dependent variable.
    - Objective: to refine prediction of hospitalization or readmission.

This multi-level statistical design can identify at-risk populations, guide innovative interventions, and integrate care for targeted groups. Such an approach yields insight into how individual, societal, and health system factors influence healthcare demand, helping reduce unnecessary utilization, lower costs, and design new capitation models for effective population health management.

Demand drivers. Utilization patterns, particularly under universal health insurance systems, can be tracked through ambulatory and inpatient care. Evidence shows that populations in Asia generally use more services than those in the United States (1), with demand increasing due to aging demographics. This

trend threatens sustainability and calls for new cost-containment and care management strategies, including better continuity and coordination of care (1, 2).

Editorial objectives. This editorial seeks to:

1. Identify a population health management approach to control uncontrolled demand growth through risk identification and stratification.
2. Evaluate the effectiveness of care management strategies in addressing challenges such as aging populations, workforce shortages, system inefficiencies, rapid changes or disruptive innovations, and rising home healthcare needs.

Future studies, guided by Andersen's Behavioral Model, should examine:

- Can service use be segmented into homogeneous subgroups to reveal patterns in utilization?
- What behavioral, personal, and social determinants influence service use in each subgroup?
- How do care management strategies affect efficiency and outcomes?
- How can delivery systems be optimized for effectiveness and sustainability?

To answer the above questions, we expand the version of Andersen and Newman's conceptual model of health service utilization to classify the individual, societal, and health system determinants into the predisposing, enabling, and need for care factors (3–7). The analytic methods include: 1) the first stage least squares analysis, using demographic and social factors as predictors of health services to stratify the patient population; 2) the second stage least squares analysis, using behavioral and health status factors as predictors of the residual variance in health services used; and 3) the ability of the difference-in-differences analysis between the pre- and post-intervention periods for multiple subgroups

TABLE 1 Implementation and evaluation of care management strategies under the National Health Insurance in Taiwan (1995–2025).

Care management programs and strategies	Demand management strategies	Utilization management strategies	Quality management strategies	Engagement management strategies
Program activities	x	x	x	x
Program proximal outcomes	x	x	x	x
Program intermediate outcomes	x	x	x	x
Program distal outcomes	x	x	x	x

Check mark (x) to implement specifically designed and implemented strategies.

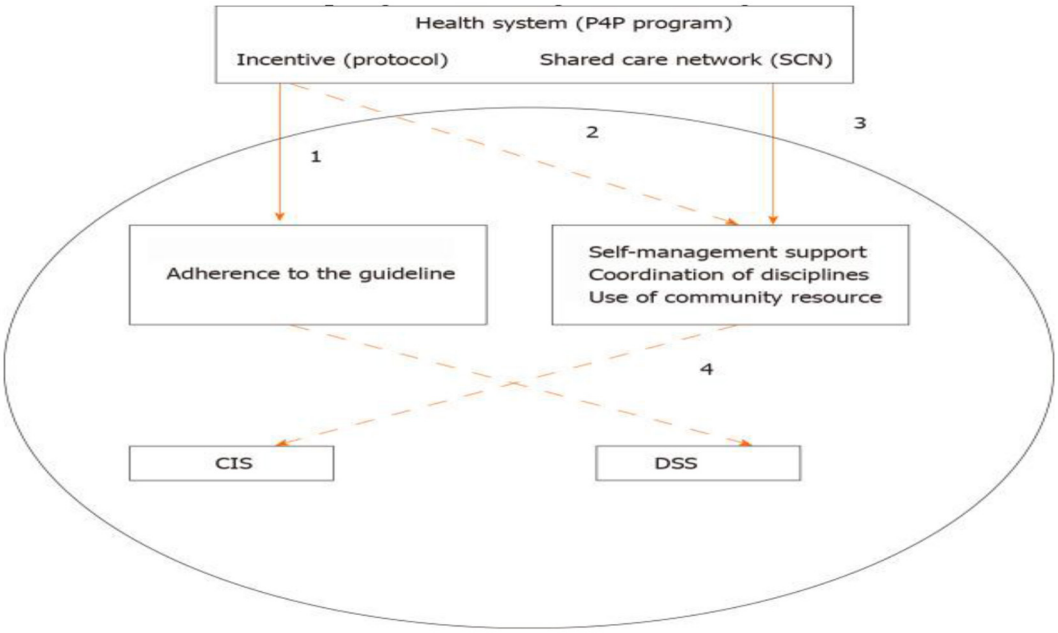


FIGURE 1
A proposed health system reform centered in adopting care management strategies. (1) Quality management, (2) utilization review & management, (3) health informatic integration and efficiency analysis, (4) engagement & production management, (5) CIS = clinical information system, and (6) DSS = optimizing decision support and administration systems.

of the targeted population can detect the benefits of multi-care management strategies (8–10).

Health services researchers have consistently documented the need to detect and identify excessive users of health services (11, 12). Interestingly, there is a paucity in the empirical literature revealing standardized criteria to classify the users since there are disparities and variations in health services use at different populations. Table 1 is a summary of relevant predictors or determinants in studying the utilization of physician services and hospitalization. Alkhawaldeh et al. (13) in a systematic review on Andersen's behavioral system model of health services utilization reported that its theoretical focus varies by perspectives and types of healthcare used. However, the consensus among researchers and scholars in health services research suggests that the enabling factors, such as health insurance coverage, income and usual sources of care, exert more influences on the variability in healthcare utilization than the predisposing factors (14). Furthermore, the need for care factors, such as perceived health and clinically determined diagnoses, are more influential than the predisposing and enabling factors (9, 11–13). After twenty years of application of behavioral model, Stein et al. (9) noted that behavioral factors are still relevant predictors of health services use. Table 1 summarizes the actual implementation of varying care management strategies and the impacts on ambulatory care and inpatient care.

3.2 Methodology

3.2.1 Design

Because randomized trials are often impractical in health services research, we propose a quasi-experimental design using pre–post comparisons with control groups that could be matched by using the propensity score matching and analysis. This design allows detection of intervention effects at both patient and provider levels while maintaining ethical feasibility (15, 16).

3.2.2 Measurements

- Dependent variable: healthcare utilization (ambulatory care, home care, nursing home care, hospitalization, etc.).
- Stage 1 predictors: predisposing factors (e.g., age, gender, marital status, rural–urban residence, distance to service centers, types of health insurance system).
- Stage 2 predictors: enabling and need factors, used to explain residual variance from Stage 1.

3.2.3 Analytics

- Stage 1: Automatic interaction detector (AID) or classification and regression tree (CART) methods to identify homogeneous subgroups (e.g., high users).
- Stage 2: Regression models using residual variance from Stage 1 as the dependent variable.
- Difference-in-differences (DID): compares pre- and post-intervention outcomes across groups, controlling for variability with propensity score matching.
- Equation: DID = (b–a)/[(a+b)/2] (b – a)/[(a + b)/2] (b–a)/[(a + b)/2] × 100, where a = pre-intervention outcome, b = post-intervention outcome.

This quasi-experimental, multi-stage design enables evaluation of the net impact of management interventions, providing actionable evidence for health system innovation.

3.3 Implications

Healthcare demand is shaped by eight critical factors:

1. Population aging
2. Workforce shortages
3. Rising chronic disease burden
4. Growth in home healthcare needs
5. Inequities in access to quality care
6. Availability of integrated care
7. Disruptive health information technologies and innovations
8. Develop and use artificial intelligence assisted clinical care support

No single intervention can address these challenges. However, integrated care management strategies—combining demand management, utilization management, quality improvement, and patient engagement—offer a viable path forward.

Table 1 summarizes the implementation of care management strategies under Taiwan's National Health Insurance (1995–2025). Figure 1 illustrates a proposed reform model centered on integrated care management, supported by clinical information systems (CIS) and decision support systems (DSS).

Together, these approaches advance population health management by aligning risk management, quality management, and patient engagement with informatics-driven efficiency analysis.

4 Conclusions

We are pleased to present Volume 2 of this Research Topic, which highlights a diverse range of topics in healthcare research. The editorial team extends its sincere gratitude to the authors and reviewers whose valuable contributions made this volume possible. We anticipate that these articles will encourage global researchers to foster collaborative teams and to explore causal mechanisms that can improve the quality and efficiency of global health strategies. We also hope this editorial will inspire investigators to design and conduct scientific studies using mixed-method approaches. Finally, it is important to emphasize that healthcare services and strategies require not a single solution, but multifaceted and coordinated approaches to achieve sustainable improvements.

Author contributions

TW: Writing – original draft, Writing – review & editing. JS: Writing – original draft, Writing – review & editing. HH: Writing – original draft, Writing – review & editing.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Analysis of the coupling coordination between traditional Chinese medicine medical services and economy and its influencing factors in China

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Background: The coordinative relationship between medical treatment and the economy is an important part of promoting the sustainable and healthy development of a social economy, and it is conducive to promoting the coordinated development of the two systems.

Methods: Based on constructing a comprehensive evaluation index system for the relationship between traditional Chinese medicine medical services and economic development, the entropy method, coupling coordination model, and Tobit model are used to calculate the comprehensive development level, coupling coordination degree, and influencing factors of the two systems in 31 provinces of China from 2015 to 2021. Suggestions are proposed for the coordinated development of traditional Chinese medicine medical services, and economy.

Results: The results showed that the development level of traditional Chinese medicine was higher than that of social and economic development, the relative development gap between the two systems was gradually narrowed, and the coupling coordination degree increased steadily; however, the regional differences were large. The relative development level and coupling coordination degree of each region show a development pattern of eastern > central > western > northeast; the coupling coordination degree of the two systems in the spatial region was positively correlated and was enhanced year by year. From the perspective of influencing factors, the level of economic development is the decisive factor in the coupling and coordination between traditional Chinese medicine medical treatment and the social economy. Factors such as human capital and health level in traditional Chinese medicine have an inhibitory effect on the coordinated development of the two systems.

Conclusion: So, China should focus on optimizing the regional allocation of traditional Chinese medicine medical personnel, improving the quality of medical services, and enhancing the health level of medical personnel.

KEYWORDS

traditional Chinese medicine medical services, economic, coupling coordination, Tobit, influence factor

1 Introduction

Chinese traditional medicine has five major resource advantages in health, economy, technology, culture, and ecology (1), making indelible contributions to the lives and health of working people in China and around the world. In 2016, the State Council of China proposed in the "Outline of the Strategic Plan for the Development of Traditional Chinese

Medicine (2016–2030)" that by 2030, all traditional Chinese medicine services will be covered, and greater contributions will be made to economic and social development (2). It can be seen that the development of traditional Chinese medicine services concerns people's livelihood, and the Chinese government has been emphasizing the role of traditional Chinese medicine development in the social economy. China is facing a critical period of comprehensive construction of socialist modernization, adhering to the development concepts of innovation, coordination, green, openness, and sharing. However, the problem of imbalanced and insufficient development of traditional Chinese medicine services in China is still prominent, with problems such as unreasonable allocation of traditional Chinese medicine resources. At present, sustainable development has become an issue of the utmost importance across the world, especially after the proposed "Healthy China strategy" (3); the coordinated relationship between traditional Chinese medicine medical treatment and the social economy deserves great attention.

According to the literature review, the study on the interaction between medical and health services and the economy in some developed countries is relatively preliminary, mainly exploring the relationship between medical and health expenditure and gross domestic product (GDP) growth. Since Joseph Newhouse noticed a strong positive correlation between per capita health expenditure and per capita GDP, many scholars have devoted themselves to studying the positive correlation or causal relationship between health expenditure and economic development. Some studies have shown that improvements in health can lead to an increase in GDP and vice versa (4, 5). Hitiris and Posnett (6) used a large number of time series and cross-sectional observations to re-examine the results of previous studies, which confirmed the importance of GDP as a determinant of health expenditure. Mayer (7) studied whether there is a Granger causality between medical expenditure and income in 18 Latin American countries and found that there is a significant causal relationship between income and medical expenditure. Raghupathi (8) explored the relationship between public health spending and economic performance across the United States and found that citizens' health status does lead to an overall improvement in economic conditions. Wang (9) proposed that in an economically developed country, there is a high demand for medical services, and the level of medical services should meet the medical needs. Subsequently, some scholars have studied the relationship between medical and health expenditure and economic development in developing countries, and the results generally reflect that medical and health expenditure is crucial to developing countries (10–12), and there is an iterative relationship between economic growth and health-economic growth leading to human capital investment and health progress. Good population health leads to higher labor productivity and economic growth (8, 13). In developing countries, the disposable income of families is relatively low, resulting in people with poor health not only losing productivity and income but also having out-of-pocket (OOP) expenses for necessary healthcare services. Therefore, improved health in developing countries is good for productivity (13–15). Sülkü and Caner (16), Mehrara and Musai (17), and Elmi and Sadeghi (18), and other scholars used cross-sectional interface data to investigate the co-integration relationship between health expenditure and GDP in some developing countries and the causal relationship by adopting the multivariate co-integration method. Both show a strong positive correlation and prove that income is an important factor in health expenditure and growth in many developing countries. Thoa et al. (19) explored the relationship between family healthcare utilization and economic growth in the Bhavi region of Vietnam from 2003 to 2007. Economic growth in developing countries widened the gap between the rich and the poor and also increased the utilization of medical care, and families with economic growth also had better utilization of medical and health services (19). Bedir (20) explored the relationship between medical care and economic growth in developing countries and found that medical care expenditure reached the saturation level, and the impact of medical expenditure on economic growth weakened.

Most of the above studies tend to consider the single relationship between medical and health expenditure and economic development and do not conduct a quantitative assessment of the relationship between medical and economic development. Fortunately, however, the coupled coordination model allows us to study the interaction between two systems (21, 22). In recent years, the coupled coordination model has been applied to a certain extent in China's medical and health field, but it started relatively late. The initial research focused on the coordination relationship between medical input and health benefits (23, 24). After that, various scholars began paying attention to the coupling and coordination of research between medical services and economic development (25–28). The coupling study of traditional Chinese medicine medical treatment and economic development level is subsequent. At present, the coupling coordination model is mainly used to study the regional coupling coordination degrees (29), the coupling coordination degree between China's overall traditional Chinese medicine service ability and regional economy (30), and use spatial analysis methods to explore the spatiotemporal evolution characteristics of coupling coordination degree (31). In general, there are more studies on the causal relationship and co-integration relationship between medical care and social economy and fewer studies on the coupling mechanism of traditional Chinese medicine medical care and social and economic development and the influencing factors of the coupling development of the two systems.

Therefore, the research objective of this article is first to sort out the interaction relationship between traditional Chinese medicine medical services and economic development, then calculate the comprehensive development level of traditional Chinese medicine medical services and economy in 31 provinces of China from 2015 to 2021, couple and coordinate, and explore the influencing factors of coupling and coordination. Finally, policy recommendations are proposed. The contribution of this study is to expand the international empirical research on the coupling of healthcare and economy from a bidirectional perspective and enrich relevant theoretical research. The combination of

Abbreviations: GDP, Gross Domestic Product; D, coupling co-scheduling; F, Relative development degree; Tcmp, traditional Chinese medicine personnel; Gov, Government's medical expenditure capacity; Pop, population distribution; Led, Economic development level; Pdr, Population health; Train, Transportation infrastructure level; Indu, industrial structure.

mathematical statistics and exploratory spatial data analysis can be used to explore the degree of coupling and coordination between economic development and medical services in different countries. Showcasing the coordination status and regional imbalance characteristics between traditional Chinese medicine and the economy is conducive to promoting the sustainable and healthy development of China's medical and health industry and economy.

2 The coupling mechanism between traditional Chinese medicine and economic development

2.1 Traditional Chinese medicine medical services can effectively promote economic development

The development level of traditional Chinese medicine medical services is one of the important guarantees for economic development. Only from the perspective of medical and healthcare does traditional Chinese medicine have two functions: economy and public health (32). The development of traditional Chinese medicine contributes to the strategy of "Healthy China", and the direct effect of traditional Chinese medicine on social and economic development can be reflected in the following ways:

(1) Traditional Chinese medicine medical services have spurred the emergence of new industries and provided more employment opportunities. The combination of traditional Chinese medicine services with smart healthcare, artificial intelligence technology, chronic disease treatment, medical and older adults care integration, tourism, and other industries in China has formed emerging industries. Medical institutions provide jobs. It includes the employment of professionals such as traditional Chinese medicine physicians, pharmacists and nurses, as well as employment opportunities in the pharmaceutical industry chain, such as the cultivation, processing and sales of medicinal materials. The development of the traditional Chinese medicine medical industry can create large numbers of employment and entrepreneurial opportunities, contributing to economic growth and employment.

(2) The core purpose of traditional Chinese medicine medical services is to enhance the health stock of residents. Mayer (7) and Mushkin (33) put forward the human capital theory that health, as an important human capital input, is one of the sources of economic growth An increase in the health of the population means an increase in effective working hours and productivity, which in turn affects economic development. Relevant studies have shown that healthy human capital, as an input factor of final product production, can directly promote economic growth (34–36).

(3) The growth of demand for medical services can optimize the economic structure. The demand for health consumption determines consumption expenditure, and the medical consumption expenditure generated by the demand for health services is the most basic livelihood consumption. The provision and demand for medical and health services are usually accompanied by an increase in medical consumption expenditure. The health consumption expenditure of individuals, enterprises, and governments can stimulate the demand of related industries, thereby driving economic growth. The improvement of health levels also increases the demand for health consumption of medical insurance and drives the development of the health service industry. Therefore, the improvement of health levels is conducive to the optimization and upgrading of the economic structure (37, 38). With the improvement of medical and health standards, people's demand for medical services also increases. This promotes the development and expansion of the medical industry and stimulates the growth of medical-related industries. Bhargava et al. (39) found that as the level of public healthcare services improves, it increases the health consumption expenditure of residents, leading to a significant improvement in the economic performance of developing countries.

2.2 Economy is the material foundation of traditional Chinese medicine medical services

Social and economic activities also play a decisive role in restricting development levels, service efficiency, and the structure of traditional Chinese medicine medical services. The level of economic development restricts the level of traditional Chinese medicine medical services, and economic development is the foundation of traditional Chinese medicine medical services. It is mainly reflected in the following aspects:

(1) The prosperity of the economy promotes the upgrading of the structure of the traditional Chinese medicine medical industry. Kamanda et al. (5) found that the total economic output affects the input of traditional Chinese medicine medical resources. Generally speaking, the larger the regional economic output, the more investment is made in medical and health service resources. With the prosperity and development of the economy, the government will invest more financial funds into the medical and health service industry, leading to the emergence of more medical and health institutions, which is conducive to expanding the medical service market. In order to improve medical service capabilities, medical service entities will be committed to researching and developing new medical equipment and technologies, promoting innovation and upgrading industrial technology in the medical service industry, and injecting new vitality into the medical service industry.

(2) Economic development affects the allocation of traditional Chinese medicine medical and health resources. The layout of economic development also affects the layout of traditional Chinese medicine medical institutions, the layout structure of traditional Chinese medicine medical services will automatically adapt to the form of economic development and meet the needs of economic development. Economic activities also play an important role in promoting the structural layout, medical service level, and service efficiency of traditional Chinese medicine medical institutions. First, regions with higher levels of economic development attract a large population agglomeration, which affects the demand for medical and health services. Therefore, the layout structure of traditional Chinese medicine medical treatment will automatically adapt to the form of economic development and meet the needs of economic development.

(3) Economic development also affects the local concept of medical treatment, improving health levels. Family capital determines patients' choice of medical treatment. Generally speaking, families in economically developed areas have sufficient family capital and will directly choose medical treatment (40). Residents in economically underdeveloped areas generally choose to delay medical treatment, give up medical treatment or borrow medical treatment, which leads to loss of local human resources, human damage, and curb social and economic development. Personal income is also important for healthcare. Grossman (41) stated that a consumer's demand for health and medical care should be positively correlated with his wage rate. Raghupathi (8) and Tang et al. (37) pointed out that increasing economic income can lead to better nutrition, preventive treatment, good sanitation facilities, and safe drinking water, resulting in high-quality healthcare that improves health.

Overall, traditional Chinese medicine medical services and economic development are not solely promoted, but they have a close mutual promotion effect. The relationship between healthcare and the economy is interdependent and mutually reinforcing. The development of the economy provides strong support and impetus for traditional Chinese medicine, and the progress of traditional Chinese medicine also provides a solid guarantee and driving force for economic development. Therefore, we should strengthen our attention to the integration and interaction between healthcare and the economy, promote their coordinated development, and contribute to high-quality economic development and people's health.

3 Research design

3.1 Construction of indicator system

3.1.1 Selection of traditional Chinese medicine medical service indicators

The selection of comprehensive evaluation indicators in this study refers to previous relevant studies (25, 42, 43). On the basis of organizing relevant research results, based on the availability, independence and scientificity of the indicators, the comprehensive evaluation index system of this study was determined.

Traditional Chinese medicine medical institutions are one of the main bodies of medical and health services in China. Traditional Chinese medicine medical and health institutions can reflect the distribution density of medical and health services (42), and their quantity and quality may directly affect the future of traditional Chinese medicine services. Traditional Chinese medicine medical institutions, the number of traditional Chinese medicine beds, and traditional Chinese medicine health personnel are the basis of traditional Chinese medicine medical resources, which can directly reflect the supply capacity of traditional Chinese medicine medical services. Financial investment in medical and healthcare can reflect the financial guarantee of medical and healthcare. This research employed the financial allocation of traditional Chinese medicine medical institutions and the revenue and expenditure ratio of traditional Chinese medicine hospitals to reflect the financial guarantee of traditional Chinese medicine medical care. The financial allocation of traditional Chinese medicine medical institutions is an important factor in embodying policy support. The income and expenditure ratio of traditional Chinese medicine hospitals mainly reflects the profit situation of hospitals. This study selected indicators such as the number of diagnosis and treatment visits, discharge visits, per capita daily diagnosis and treatment visits by physicians in traditional Chinese medicine hospitals, per capita daily hospitalization days by physicians in traditional Chinese medicine hospitals, utilization rate of beds in traditional Chinese medicine hospitals, and average hospitalization days in traditional Chinese medicine hospitals to reflect the status of traditional Chinese medicine medical and health services. The average length of stay and the utilization rate of beds are the core indexes to measure the efficiency of ward work, and the average length of stay reflects the ability and efficiency of medical service. The utilization rate of beds is not only an important indicator for measuring the efficiency of wards but also an important indicator for evaluating the management capacity of hospitals and wards. The amount of traditional Chinese medicine consultation and treatment is a key indicator that reflects the utilization of traditional Chinese medicine services and its influencing factors (43). It can also reflect people's trust in traditional Chinese medicine medical services from the side.

3.1.2 Selection economic indicators

Economic aggregate is an important indicator for measuring the development level of a regional economic scale, which can represent the economic strength of a country or region. This study used GDP, local general public budget revenue (100 million yuan), total retail sales of social consumer goods (100 million yuan) and other indicators to measure China's economic aggregate. The economic structure is of great significance to the healthy and sustainable development of the economic system. A reasonable and adaptable economic structure helps to improve the overall efficiency and competitiveness of the economic system and promote the healthy development of the economy. This study uses the proportion of the primary, secondary, and tertiary industries to represent the economic structure. Economic benefit is an index used to the income and results of economic activities. It is represented by per capita consumption expenditure, per capita disposable income (yuan), Engel coefficient, and per capita gross regional product (yuan). The specific indicator system is shown in Table 1.

3.2 Research methods

The research topic of this article is to measure the comprehensive development level, coupling coordination degree, and influencing factors of traditional Chinese medicine medical services and economic development in 31 provinces of China from 2015 to 2021. The relevant indicator data of traditional Chinese medicine medical services and economy in 31 provinces of China from 2015 to 2021 were used as research samples. China's 31 provinces are divided into four major regions, namely the eastern, central, western, and northeastern regions, as the main research and analysis areas. Therefore, relevant variables were selected from the two systems of traditional Chinese medicine services and economic development to calculate their comprehensive

TABLE 1 Evaluation index system of traditional Chinese medicine and economic development.

System	Target layer	Index layer	Direction	Weight
Traditional Chinese medicine medical system	Investment in traditional Chinese medicine resources	Traditional Chinese medicine personnel	+	0.106
		Traditional Chinese medicine medical institutions	+	0.118
		Traditional Chinese medicine beds	+	0.093
		Financial allocation for traditional Chinese medicine medical institutions	+	0.106
		Revenue and expenditure ratio of traditional Chinese medicine hospitals	+	0.094
	Volume of traditional Chinese medicine services	Traditional Chinese medicine medical institutions diagnose and treat people/10,000 people	+	0.121
		Number of discharged patients/person from traditional Chinese medicine medical institutions	+	0.106
		Per capita daily diagnosis and treatment by doctors in traditional Chinese medicine hospitals	+	0.123
		Physicians in traditional Chinese medicine hospitals are responsible for daily hospitalization days per person	+	0.050
	Efficiency of traditional Chinese medicine services	Bed usage rate in traditional Chinese medicine hospitals/%	+	0.049
		Average hospitalization days/day in traditional Chinese medicine hospitals	−	0.034
Economic development system	Economic aggregate	Gross regional product	+	0.111
		Local general public budgeting revenue (100 million yuan)	+	0.193
		Total retail sales of social consumer goods/100 million yuan	+	0.120
	Economic structure	Proportion of the primary sector of the economy	−	0.029
		Proportion of the secondary sector of the economy	+	0.029
		Proportion of the tertiary sector of the economy	+	0.122
	Economic benefits	Per capita consumption expenditure by region	+	0.122
		Per capita disposable income (yuan)	+	0.138
		Engel's coefficient	−	0.033
		Per capita gross regional product (yuan)	+	0.104

The data in this study are a panel data set, and the weight of indicators in the table is the average weight value from 2015 to 2021.

development level, and a coupling coordination model was used to calculate their coupling coordination scheduling. The Tobit model was used to calculate the factors influencing the coupling coordination degree in the four major regions. The research object of this article is 31 provinces in China. The data sources for this study were all from the China Statistical Yearbook, China Health Statistical Yearbook, and Statistical Extracts of Chinese Traditional Medicine from 2016 to 2022. Hong Kong, Macau, and Taiwan Provinces were not included in the analysis due to their inconvenient data collection.

(1) Entropy method

The size of indicator data was different, and there were differences in positive and negative orientations. The *Min-Max* method was adopted to standardize the data to ensure that the value of all indicator data was between 0 and 1. *i* represents the province and *j* represents the indicator, and the formula is as follows:

$$\text{Positive indicator}: X'_{ij} = \frac{X_{ij} - Min_{ij}}{Max_{ij} - Min_{ij}}$$

$$\text{Negative indicator}: X'_{ij} = \frac{Max_{ij} - X_{ij}}{Max_{ij} - Min_{ij}}$$

where Min_{ij} and Max_{ij} represent the minimum and maximum value of j index in province i, respectively, and X_{ij} represents the value of j index in province i. X'_{ij} is the normalized value. $i = 1,2,3...m, j = 1,2,3...n$.

First of all, the weight of each indicator is measured. The formula is as follows:

$$P_{ij} = \frac{X'_{ij}}{\sum_{i=1}^{m} X'_{ij}}$$

where P_{ij} is the proportion value of j indicators in the i region. Then the information entropy value e_j. The formula for information entropy is as follows:

$$e_j = -k\sum_{i=1}^{m} P_{ij}Ln(P_{ij} + 0.0001),\ 0 \le e_j \le 1$$

where $k = \frac{1}{\ln_m}$. Finally, the indicator weights of the traditional Chinese medicine and economic development system are calculated.

$$w_j = \frac{(1 - e_j)}{\sum_{j=1}^{n}(1 - e_j)}$$

where $w_j \in [0,1]$, and the sum of all terms is 1, $\sum_{j=1}^{n} w_j = 1$.

The standard values and weights of each indicator are obtained to calculate the comprehensive evaluation value U of each system U_1, U_2. Comprehensive evaluation function. The formula is as follows:

$$U_{i=1,2} = \sum_{j=1}^{n} X'_{ij}W_j$$

where U_1 is the comprehensive evaluation value of traditional Chinese medicine, U_2 is the comprehensive evaluation value of economic development. X'_{ij} is the standardized number, and X'_{ij} is the indicator weight.

(2) Coupling coordination model

The coupling degree refers to the interaction and influence between two or more systems, reflecting the degree of interdependence and constraints between systems (31, 44). This study uses a coupled coordination model to calculate the coupled coordination scheduling between traditional Chinese medicine and social economy. The coupling formula for the two systems is as follows:

$$C = 2 * \left\{U_1U_2/(U_1 + U_2)^2\right\}^{1/2}$$

where C is the coupling degree between the two, where $C \in [0,1]$. Relying solely on coupling degree discrimination may be misleading, and a coupling coordination degree model needs to be established, namely:

$$T = aU_1 + \beta U_2$$
$$D = \sqrt{C * T}$$

TABLE 2 Hierarchy of coupling coordination between traditional Chinese medicine and economic development.

Coordination level	*D*-value	Coupling development type
Low-level coordination (antagonistic period)	(0–0.1)	Extreme dysregulation and decline
	(0.1–0.2)	Severe dysregulation and decline
	(0.2–0.3)	Moderate dysfunctional decline
	(0.3–0.4)	Minor disorder
Middle-level coordination (break-in period)	(0.4–0.5)	Proximity coordination (transitional)
	(0.5–0.6)	Barely coordinated (transitional)
	(0.6–0.7)	Primary coordination
High-level coordination (coordination period)	(0.7–0.8)	Intermediate coordination
	(0.8–0.9)	Well-coordination
	(0.9–1)	High-quality coordination

where D is coupling co-scheduling, T is coordination index, α, β is an undetermined coefficient that satisfies $\alpha + \beta = 1$—assuming that both contribute equally to the coordinated development of coupling, i.e., $\alpha = \beta = 0.5$. The level division of coordination degree between the two systems is shown in Table 2.

(3) Tobit panel model

Due to the coupling coordination degree being between 0 and 1 and being a restricted dependent variable, a panel Tobit model can be used to analyze the influencing factors of the coordination degree between the two systems. To avoid multicollinearity and heteroscedasticity, logarithmic treatment is applied to all explanatory variables. The model formula is constructed as follows:

$$D_{it} = y_0 + y_1\, lnTcmp_{it} + y_2 lnGov_{it} + y_3 lnPop_{it} + y_4 lnLed_{it} + y_5 lnPdr_{it} + y_6 lnTrain_{it} + y_7 lnIndu_{it} + \varepsilon_i$$

In the formula, D_{it} is coupled co-scheduling; y_0 is a constant term; Tcmp represents human capital in traditional Chinese medicine, while gov represents government financial capacity in healthcare; Pop represents population density, Led represents economic development level, Pdr represents population mortality rate, Train represents transportation infrastructure, and Indu represents industrial structure. I represents each province, and t represents time; it is a random perturbation term.

4 Research results and analysis

4.1 The comprehensive development level of traditional Chinese medicine medical services and social economy

The comprehensive development coefficient of traditional Chinese medicine (U1), and the comprehensive development coefficient of social and economic (U2) were arithmetically

averaged, respectively, so as to indicate the average development level of the two systems in each region during 2015–2021. In addition, based on U1/U2 = F, the relative development degree of the two systems is calculated. An *F*-value of <0.8 indicates that the development of traditional Chinese medicine is lagging behind the level of economic development. Notably, 0.8 < F < 1.2 indicates that the two systems are developing synchronously. If F > 1.2, it indicates that the level of traditional Chinese medicine is leading the development of economic development. China's 31 provinces are divided into four regions (eastern, central, western, and northeastern) for analysis.

As shown in Table 3, The u1 in the eastern region increased from 0.409 in 2015 to 0.392 in 2021, indicating that the traditional Chinese medicine medical level in the eastern region of China has slightly decreased in recent years, but U2 rose from 0.312 to 0.486, denoting that the social and economic development level in the eastern region has greatly improved from 2015 to 2021. In 2021, U1 and U2 were 0.392 and 0.486, respectively, indicating that the social and economic development was ahead of the development level of traditional Chinese medicine. The *F*-value decreased from 1.355 to 0.890, demonstrating that the gap between the two systems gradually narrowed and synchronous development was achieved. The central U1 increased from 0.367 to 0.373, indicating that Chinese medicine in the central region was seeking progress while maintaining stability. The rise of U2 from 0.156 to 0.270 indicates that the level of social and economic development in the central region has risen sharply, and the level of traditional Chinese medicine medical treatment is higher than the level of economic development. The *F*-value decreased from 2.348 in 2015 to 1.373 in 2021, which reveals that the gap between the two systems is narrowing and gradually tends to be synchronized. U1 in the western region changed from 0.326 to 0.328, which denotes that the level of traditional Chinese medicine in the west has not been greatly improved and has developed steadily. U2 increased from 0118 to 0.175, which indicates that the social economy of the western region has improved to a certain extent in recent years, and the level of traditional Chinese medicine is higher than the level of social and economic development. The F-value also changed from 2.852 in 2015 to 1.919 in 2021, which demonstrates that the gap between the medical level and the level of social and economic development in the western region is gradually narrowing and tends to develop simultaneously. In Northeast China, U1 changed from 0.225 to 0.184, indicating that the level of traditional Chinese medicine in Northeast China is gradually decreasing, and U2 changed from 0.306 to 0.177, denoting that the social economy in Northeast China has not improved in recent seven years, but has declined rapidly. The *F*-value changed from 1.014 in 2015 to 1.148 in 2021, indicating that the development gap between traditional Chinese medicine and social economy in Northeast China has gradually widened.

As shown in Table 3, in 2021, the average value of U1 and U2 in the overall region of China was 0.343 and 0.294, respectively, which denotes that the level of traditional Chinese medicine medical treatment is generally higher than the level of social and economic development. The F-value changes from 2.094 to 1.407, which indicates that the development gap between the two systems in China is gradually decreasing, and the development balance of the two systems is rising and tends to be stable on the whole. It can be seen that in recent years, China has focused on coordinated development strategy has achieved certain results in medical and economic aspects. With the exception of Northeast China, both the level of traditional Chinese medicine medical services and the level of social and economic development in China decrease from east to west, and the level of social and economic development in Northeast China is not much different from that in western China. The development level of traditional Chinese medicine and social and economic development is developing simultaneously only in the eastern region, and the development level of the two systems is gradually increasing from the east to the west, but the development gap between the two systems in the central and western regions tends to develop simultaneously. In general, the levels of medical development in China are higher than the level of economic development, and the development level of the two systems presents the distribution characteristics of "the highest in the east, followed by the middle and west, and the lowest in the northeast." Yang Huan's study also obtained similar results (45).

4.2 The coupling and coordination characteristics of traditional Chinese medicine medical services and economy

4.2.1 Time series evolution of coupling coordination

As can be seen from Table 4, in 2015, there were five provinces with mild imbalances (0.3–0.4), 12 on the verge of coordination (0.4–0.5), eight barely coordinated (0.5–0.6), five primarily coordinated (0.6–0.7), and 1 with intermediate coordination (0.7–0.8). It can be seen that the coordination degree of China's two systems in 2015 was mainly near coordination and barely coordination, which belongs to the middle level of coordination (run-in period). The stability of middle-level coordination is not strong and belongs to the transitional type. If the force point inside the two systems can be found, the coupling coordination will rise to the coupling period; on the contrary, it is easy to fall to the low - level coordination (antagonistic period). In 2021, there were four mildly dysfunctional provinces, 10 on the verge of coordination, nine barely coordinated, three with primary coordination, four with intermediate coordination, and one well-coordinated. The low-level coordination provinces decreased, and the middle and high-level coordination provinces increased, which shows that the overall coordination level gradually shifted upward.

As can be seen from Table 4, from 2015 to 2021, the coordination degree between traditional Chinese medicine medical treatment and social economy in China increased from 0.497 to 0.541. The two systems in China have risen from near imbalance to barely coordinated, and the average rate of increase of the degree of coordination between the two systems was 0.04%. Eastern rose from 0.581 to 0.640, an increase of 0.06%. The central region increased by 0.559 from 0.486, an increase rate of 0.07%. The west rose from 0.433 to 0.480, an increase of 0.05%. The northeast decreased from 0.496 to 0.420, with an increase of −0.08%. The reason for the decline of coordination degrees in Northeast China may be that there are only three provinces in Northeast China, which are mainly dominated by the secondary industry, a remote

10.3389/fpubh.2024.1320262

TABLE 3 Comprehensive development level degree of traditional Chinese medicine and social economy in China.

	Year	2015	2021	2015	2021	2015	2021
	Province	U1	U1	U2	U2	F	
Eastern	Beijing	0.346	0.263	0.462	0.684	0.749	0.384
	Tianjin	0.221	0.145	0.302	0.363	0.733	0.401
	Hebei	0.383	0.431	0.164	0.247	2.339	1.748
	Shandong	0.524	0.554	0.308	0.449	1.700	1.233
	Jiangsu	0.544	0.489	0.388	0.653	1.402	0.748
	Zhejiang	0.579	0.526	0.347	0.584	1.669	0.900
	Shanghai	0.400	0.353	0.441	0.708	0.908	0.498
	Fujian	0.318	0.320	0.219	0.381	1.451	0.841
	Guangdong	0.691	0.695	0.389	0.655	1.777	1.061
	Hainan	0.084	0.148	0.102	0.137	0.823	1.081
	Eastern mean	0.409	0.392	0.312	0.486	1.355	0.890
Northeast China	Liaoning	0.240	0.166	0.231	0.252	1.038	0.659
	Jilin	0.204	0.207	0.544	0.157	0.376	1.315
	Heilongjiang	0.231	0.179	0.142	0.122	1.629	1.470
	Northeast average	0.225	0.184	0.306	0.177	1.014	1.148
Central section	Shanxi	0.212	0.222	0.150	0.199	1.412	1.117
	Anhui	0.326	0.373	0.132	0.289	2.465	1.292
	Jiangxi	0.321	0.316	0.118	0.225	2.716	1.406
	Henan	0.492	0.554	0.173	0.293	2.840	1.892
	Hubei	0.421	0.370	0.191	0.320	2.204	1.158
	Hunan	0.427	0.401	0.174	0.291	2.453	1.377
	Middle mean	0.367	0.373	0.156	0.270	2.348	1.374
West	Inner Mongolia	0.270	0.243	0.187	0.224	1.444	1.086
	Guangxi	0.372	0.404	0.100	0.150	3.708	2.696
	Chongqing	0.365	0.376	0.170	0.274	2.145	1.373
	Sichuan	0.734	0.733	0.165	0.297	4.439	2.469
	Guizhou	0.295	0.338	0.083	0.150	3.544	2.261
	Yunnan	0.382	0.390	0.098	0.177	3.900	2.204
	Tibet	0.193	0.164	0.074	0.097	2.606	1.687
	Shaanxi	0.340	0.307	0.142	0.227	2.395	1.351
	Gansu	0.320	0.308	0.085	0.108	3.762	2.848
	Qinghai	0.167	0.208	0.094	0.114	1.774	1.822
	Ningxia	0.158	0.204	0.112	0.145	1.414	1.408
	Xinjiang	0.317	0.257	0.102	0.141	3.094	1.820
	Western mean	0.326	0.328	0.118	0.175	2.852	1.919
	National average	0.351	0.343	0.206	0.294	2.094	1.407

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TABLE 4 Coupling coordination degree of Traditional Chinese Medicine and Economy in China from 2015 to 2021.

Region	Province/city	2015	2016	2017	2018	2019	2020	2021	Rising rate
Eastern	Beijing	0.632	0.674	0.677	0.701	0.704	0.623	0.651	0.02%
	Tianjin	0.508	0.540	0.522	0.481	0.544	0.458	0.479	−0.03%
	Hebei	0.500	0.550	0.561	0.539	0.596	0.584	0.571	0.07%
	Shandong	0.634	0.695	0.699	0.660	0.724	0.702	0.706	0.07%
	Jiangsu	0.678	0.739	0.744	0.698	0.750	0.745	0.752	0.07%
	Zhejiang	0.670	0.720	0.727	0.688	0.746	0.737	0.744	0.07%
	Shanghai	0.648	0.689	0.694	0.648	0.642	0.684	0.707	0.06%
	Fujian	0.514	0.556	0.554	0.529	0.583	0.577	0.591	0.08%
	Guangdong	0.720	0.802	0.808	0.742	0.814	0.821	0.822	0.10%
	Hainan	0.304	0.338	0.322	0.311	0.398	0.407	0.378	0.07%
	Eastern mean	0.581	0.630	0.631	0.600	0.650	0.634	0.640	0.06%
The Northeast	Liaoning	0.485	0.502	0.501	0.456	0.539	0.469	0.452	−0.03%
	Jilin	0.577	0.438	0.459	0.422	0.479	0.420	0.425	−0.15%
	Heilongjiang	0.425	0.446	0.443	0.414	0.466	0.373	0.384	−0.04%
	Northeast average	0.496	0.462	0.468	0.431	0.495	0.421	0.420	−0.08%
Central region	Shanxi	0.423	0.462	0.447	0.432	0.530	0.460	0.459	0.04%
	Anhui	0.455	0.516	0.523	0.495	0.561	0.566	0.573	0.12%
	Jiangxi	0.441	0.483	0.477	0.455	0.509	0.510	0.516	0.08%
	Henan	0.540	0.594	0.600	0.576	0.657	0.634	0.635	0.10%
	Hubei	0.532	0.574	0.578	0.547	0.624	0.571	0.586	0.05%
	Hunan	0.522	0.567	0.571	0.542	0.611	0.589	0.584	0.06%
	Middle mean	0.486	0.533	0.533	0.508	0.582	0.555	0.559	0.07%
West	Inner Mongolia	0.474	0.504	0.508	0.475	0.514	0.480	0.483	0.01%
	Guangxi	0.439	0.606	0.478	0.458	0.501	0.492	0.496	0.06%
	Chongqing	0.499	0.531	0.538	0.506	0.568	0.556	0.567	0.07%
	Sichuan	0.590	0.649	0.662	0.621	0.702	0.680	0.683	0.09%
	Guizhou	0.396	0.427	0.437	0.422	0.468	0.458	0.474	0.08%
	Yunnan	0.440	0.475	0.471	0.448	0.520	0.514	0.512	0.07%
	Tibet	0.345	0.320	0.341	0.359	0.365	0.332	0.356	0.01%
	Shaanxi	0.469	0.504	0.508	0.485	0.517	0.498	0.514	0.05%
	Gansu	0.406	0.435	0.433	0.414	0.459	0.441	0.427	0.02%
	Qinghai	0.355	0.384	0.402	0.383	0.411	0.404	0.393	0.04%
	Ningxia	0.364	0.400	0.462	0.434	0.428	0.387	0.415	0.05%
	Xinjiang	0.424	0.441	0.453	0.420	0.484	0.405	0.436	0.01%
	Western mean	0.433	0.473	0.474	0.452	0.495	0.471	0.480	0.05%
	Nationwide	0.497	0.534	0.536	0.508	0.562	0.535	0.541	0.04%

location with a low population density. It can be seen that the development rate of coupling coordination degree in central and eastern regions was the fastest, and the western region was also catching up. However, the reason why China's overall development speed is relatively slow is that the coupling and coordination degrees of the two systems in the northeast region is declining, and the decline speed is evident.

China is a vast region. In order to more directly show the spatial distribution characteristics of the coupling coordination degree of various provinces and regions in China, the ArcGis10.8 software was used in this study to visually compare and analyze the coupling coordination degrees of two systems in various regions of China in 2015, 2018, and 2021, as shown in Figure 1.

This is shown in Figure 1A; in 2015, the provinces with youth imbalance were scattered mainly in the western provinces of Tibet, Qinghai and Guizhou, and the eastern provinces of Hainan. The provinces at risk of coordination were scattered across China: Xinjiang, Gansu, Inner Mongolia, Heilongjiang, Liaoning, Shaanxi, Shanxi, Hebei, Yunnan, Chongqing, Guangxi, Jiangxi, and Anhui. The provinces that were barely coordinated were mainly in the central region, namely Sichuan, Hubei, Henan, Fujian, and Jilin. The primary coordination provinces were Beijing, Shandong, Jiangsu, and Zhejiang. The province with the best degree of coordination was Guangdong Province, which had intermediate coordination in 2015. Guangdong Province, the province with the highest degree of coordination, has been far ahead. This is mainly due to the superior geographical location of Guangdong Province and the good mass base of traditional Chinese medicine (46).

This is shown in Figure 1B; after 3 years of development, the coupling coordination degrees of various regions in China changed to a certain extent in 2018. In Ningxia, Sichuan, Guizhou, and Chongqing, the coupling coordination degree of these provinces has increased by one level. As for the coastal areas, the changes are less, and Jilin in northeast China has decreased from barely coordinated to nearly coordinated. In other provinces, there was no significant change.

This is shown in Figure 1C; compared with 2015, the coupling degree of each province in 2021 was more perceivable. The eastern coastal areas, such as Shandong, Jiangsu, Zhejiang, and other areas, have been greatly developed from barely coordinated to primary coordination. Because these provinces have better economic foundation development, higher per capita income, higher health literacy than the central and western regions, and wide coverage of transportation infrastructure, the overall accessibility of medical and health resources is high. High accessibility of medical and health resources. The central and western provinces of Shaanxi, Yunnan, Jiangxi, and Anhui have also progressed from near-imbalance to barely coordinated. These provinces have a strong endowment of traditional Chinese medicine resources and a certain mass base; thus, the level of medicine development is relatively high. The coupling coordination degrees of Hainan, Xizang, and Qinghai provinces have always been slightly disordered. These three provinces are located in the periphery of China, especially in the western region, where the economic foundation of Tibet and Qinghai provinces is weak, and it is difficult to improve the coupling coordination degree. The coordination degree in Heilongjiang has significantly decreased, from near coordination to mild imbalance, which may be due to the low population density of the province in the periphery of China.

In summary, the spatial distribution characteristics of the coupling coordination degree showed a stepped development, with east > central > west > northeast. The overall coordination degree was consistent with the spatial distribution of China's economic development level, as well as with China's population line—"Hu Huanyong line", which indicates that economic development is the basis for the coordinated development of the two systems. On the whole, the economy and population have a strong influence, among which economic factors are the basic factors because economy and population will directly affect the distribution structure of medical resources.

4.2.2 Spatial autocorrelation analysis of coupling coordination degree

Based on the coupling coordination degree of relevant data, the ArcGIS software was used to measure the global autocorrelation of China and calculate the global Moran's I index of traditional Chinese medicine and economic development in 31 provinces of China from 2015 to 2021. The larger the value of Global Moran's I, the stronger the spatial agglomeration; the smaller the value, the stronger the spatial dispersion (21, 47). According to Table 5, the global Moran index of the coupling coordination degree between traditional Chinese medicine medical treatment and social and economic development is positive, and the value is expanding. In addition to the 95% significance of the global Moreland index in 2015 ($p < 0.05$), the significance test of the global Moreland index in other years was 99% ($p < 0.01$), indicating that there is a strong spatial agglomeration relationship between the coupling and coordination of traditional Chinese medicine medical treatment and social economy. The global Moran index increases gradually over time, indicating that the spatial agglomeration of the coupling coordination degree of the two systems is becoming stronger and stronger. The coupling and coordination between traditional Chinese medicine medical services and the regional economy have a strong spatial dependence on the surrounding regions. That is, if a province has a high value, the coupling and coordination degree of its neighboring provinces is also relatively high, and regional clustering is more obvious. We should pay attention to the spatial pattern of the coupling development of traditional Chinese medicine medical services and regional economy, follow the development laws of medical services and economy, encourage the construction of collaborative development mechanisms between adjacent regions, and establish cross-regional cooperation and multi-center professional cooperative alliances.

4.3 Analysis of the influencing factors of coupling co-scheduling

4.3.1 Variable selection

There are multiple factors that affect the coordinated development of traditional Chinese medicine medical services and the economy. Based on existing research and the availability of comprehensive indicator data, combined with the actual

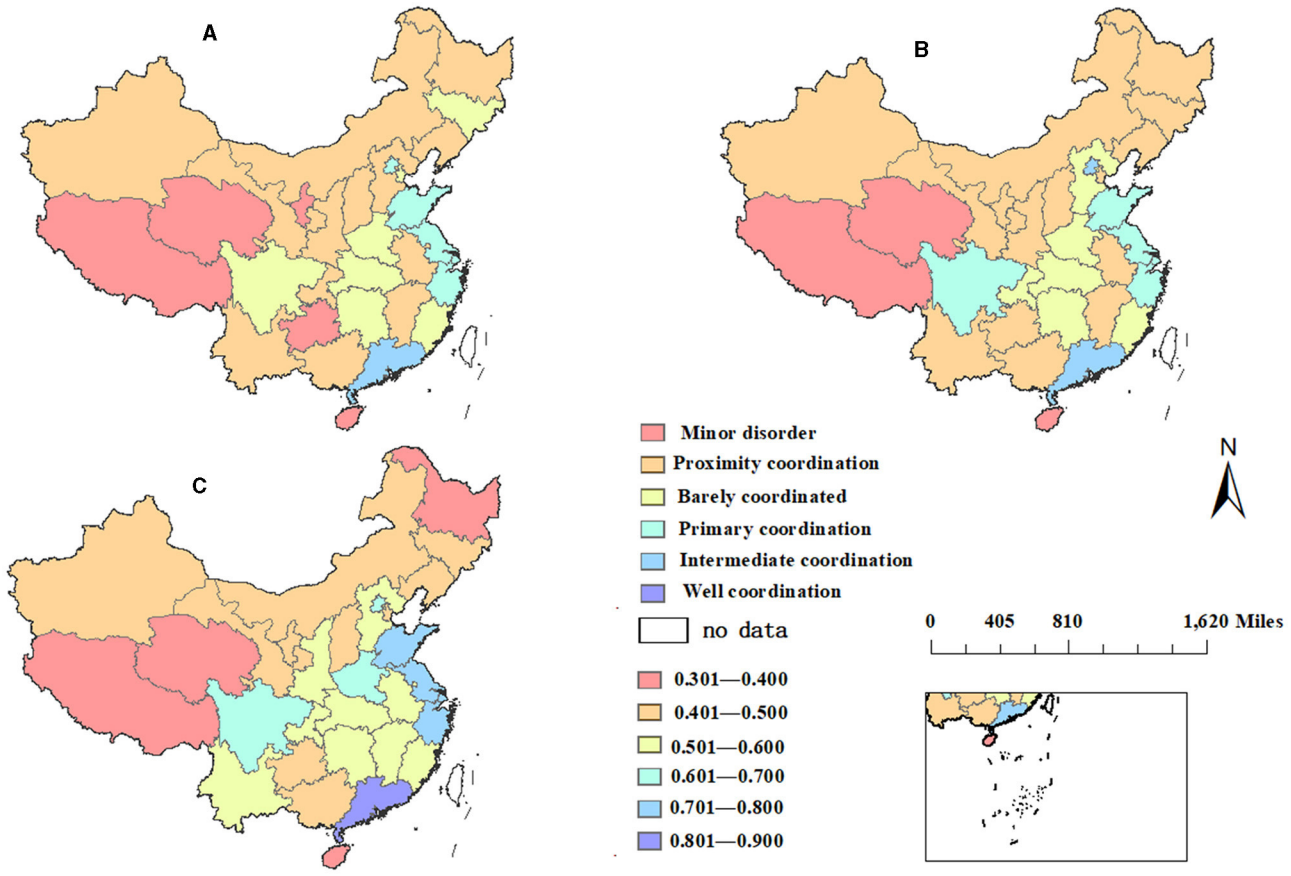


FIGURE 1
Spatial comparison of coupling coordination degree in **(A)** 2015, **(B)** 2018, and **(C)** 2021.

TABLE 5 Spatial autocorrelation table of coupling coordination degree between two systems in China.

Year	Global Moran's I	*Z*	*P*	Confidence level
2015	0.240485	2.324338	0.020107	0.950
2016	0.32513	3.049738	0.00229	0.990
2017	0.272945	2.613012	0.008975	0.990
2018	0.277691	2.642034	0.008241	0.990
2019	0.262437	2.512711	0.011981	0.950
2020	0.378086	3.496081	0.000472	0.990
2021	0.388772	3.579752	0.000344	0.990

situation in China, there are many influencing factors driving the coordinated development of the two systems. With reference to the existing studies combined with the current situation in China, this study mainly analyzes the factors influencing the two systems, from the aspects of medical personnel, medical financial expenditure, economic base, population density, health level, transportation, and industry. Finally, factors such as traditional Chinese medicine human capital (Tcmp), government medical expenditure capacity (gov), population distribution density (Pop), economic development water (Led), population health (Pdr), transportation infrastructure level (Train), and industrial structure (Indu) were determined as explanatory variables. The coupling coordination degree of 31 provinces in China from 2015 to 2021 is used as the dependent variable (see Table 6 for details). The relevant data for all explanatory variables are sourced from the China Statistical Yearbook, China Health Statistics Yearbook, and China Traditional Chinese Medicine Statistics Excerpt. Some data are obtained through secondary calculations.

TABLE 6 Factors affecting coupled co-scheduling.

	Variable name	Variable symbol	Variable description	Unit
Explained variable	Coupling coordination degree	D	Calculation results of the coupling coordination model between two systems	
Explanatory variable	Traditional Chinese medicine human capital	Tcmp	Traditional Chinese medicine personnel per thousand people = number of traditional Chinese medicine personnel at the end of the year/population * 1,000	
	Government's medical expenditure capacity	Gov	Proportion of financial expenditure on traditional Chinese medicine in healthcare expenditure	%
	Population distribution	Pop	Population density = year-end population/provincial area	%
	Economic development level	Led	Per capita disposable income	Yuan/person
	Population health	Pdr	Population mortality rate = number of deaths/year-end population	%
	Transportation infrastructure level	Train	Highway density = highway mileage/provincial area	km/km^2
	Industrial structure	Indu	Value added of tertiary sector of the economy/secondary sector of the economy	%

4.3.2 Analysis of regression results

Tcmp represents traditional Chinese medicine personnel per thousand people and represents the human capital of traditional Chinese medicine healthcare. According to Table 7, the determinability coefficient of Tcmp for the integrated development of traditional Chinese medicine and social economy in China is −0.0422, which did not pass the significance test, indicating that human capital in traditional Chinese medicine has a certain negative effect on the two systems. This may be the overall growth of the number of traditional Chinese medicine talents, but the allocation of traditional Chinese medicine talent resources was unbalanced. In some regions, the supply exceeds the demand, while in some regions, the supply is less than the demand, which leads to the inadequacy of medical human capital to promote the integrated development of the two systems. The determinability coefficient of traditional Chinese medicine medical manpower for the eastern region is −0.111. A significance test of 5% indicates that traditional Chinese medicine medical manpower capital has a significant negative effect on the coupling coordination between the two systems in the eastern region. The reason may be that the total amount of traditional Chinese medicine medical human resources in the east is large, but the demand for medical services is insufficient, resulting in the unreasonable supply and demand allocation of the total amount of medical personnel. The determinability coefficient of Northeast China is 0.129, which did not pass the significance test, indicating that traditional Chinese medicine manpower in Northeast China has a non-significant promoting effect on the coordinated development of the two systems. The total number of traditional Chinese medicine medical personnel in the northeast is insufficient, the aging is serious, and the total number of medical personnel is less than the medical demand, resulting in the human capital of traditional Chinese medicine has a certain negative effect on the coupling degree of the two systems. Traditional Chinese medicine medical human resources have a positive promoting effect on the central and western regions, with determinable coefficients of 0.0182 and 0.0146, respectively, but have not passed the significance test. It shows that there is still a large shortage of traditional Chinese medicine medical personnel in the central and western regions, and the medical personnel allocation structure is unreasonable. The regional government should also strengthen the investment and training of traditional Chinese medicine human resources.

Gov represents the government's financial expenditure on traditional Chinese medicine and is representative of the government's financial capacity. The regression coefficient of China's medical financial expenditure capacity was 0.0109, which passed the significance level test of 1%, indicating that the medical financial expenditure of traditional Chinese medicine has a positive effect on promoting the coordinated development of the two systems. Under normal circumstances, the more sufficient government financial funds are, the more investment there is in medical infrastructure and human capital cultivation. As can be seen from Table 7, the financial capacity of traditional Chinese medicine medical services has a significant promoting effect on the coordinated development of the two systems in the central, western, and northeastern regions, with determination coefficients of 0.0426, 0.008, and 0.044, respectively, and passing significance tests of 5, 10, and 1%, respectively, which reflects that China's medical financial investment is more inclined to the central and western regions. The effect of medical finance on the coordinated development of the east and northeast regions is not pronounced, indicating that the eastern has not played an obvious role in obtaining traditional Chinese medicine medical finance. The eastern region should consider reasonable planning of medical financial investment to improve the effectiveness of resource allocation.

Pop stands for population density. According to Table 7, for the whole country, its regression coefficient was 0.0329, and through the 1% significance test, it indicates that densely

TABLE 7 Tobit panel regression model results by region in China.

Dependent variable	Nationwide	Eastern region	Central region	Western region	Northeast region
Tcmp	−0.0422	−0.111**	0.0182	0.0146	0.129
	(0.031)	(0.055)	(0.045)	(0.053)	(0.114)
Gow	0.0109***	0.0070	0.0426***	0.00800*	0.0444***
	(0.003)	(0.005)	(0.012)	(0.004)	(0.015)
Pop	0.0329***	0.0231	0.176***	0.0375***	0.624**
	(0.012)	(0.056)	(0.061)	(0.013)	(0.256)
Led	0.141***	0.163***	0.103**	0.0829	0.0961
	(0.030)	(0.055)	(0.041)	(0.055)	(0.148)
Train	0.00812	0.148**	0.00722	0.00434	−0.881**
	(0.012)	(0.063)	(0.060)	(0.011)	(0.377)
Pdr	−0.107***	0.00550	−0.0129	−0.0981**	−0.0357
	(0.029)	(0.073)	(0.059)	(0.041)	(0.177)
Indu	0.00685	0.0110*	0.0171	0.00186	0.00185
	(0.004)	(0.006)	(0.035)	(0.026)	(0.006)
_cons	−0.870***	−1.343**	−1.329**	−0.291	−3.826***
	(0.309)	(0.569)	(0.579)	(0.551)	(1.304)
N	217	70	42	84	21
R^2	0.940	0.985	0.942	0.937	0.996

Standard errors in parentheses. Significance test $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

populated places have a significant positive effect on the integration and development of the two systems. The positive impact of population on the coupling coordination degree of the eastern and northeastern regions is not strong, with determination coefficients of 0.0231 and 0.0231, respectively, which did not pass the significance test. The population density in the eastern region is too dense, which may also cause a surplus of labor force, increase the medical burden, and bring greater pressure on social and economic development. Population density has no evident positive effect on Northeast China, which is mainly affected by the serious population loss and low fertility rate. The regression coefficients of population density in the central and western regions were 0.176 and 0.0375, respectively, and both passed the significance test of 1%, indicating that population density has a relatively significant effect on the coordinated development of the two systems in the central and western regions.

Led represents per capita disposable income, a measure of economic level. According to Table 7 for the whole region of China, the regression coefficient of per capita disposable income was 0.141 and passed the significance test of 1%, which indicates that the level of economic development is the most important factor in promoting the coordinated development of the two systems. For the whole country, the economic level plays a positive role in the coordinated development of the two systems. Research shows that the higher the level of economic development, the greater the total investment in medical resources will be, thus effectively having healthy human capital and promoting social and economic development. As can be seen from the table, the coefficients of the eastern and central regions were 0.163 and 0.103, respectively. The tests of 1 and 5% indicate that the social and economic development levels of the eastern and central regions are relatively high, and traditional Chinese medicine is adapted to the current level of economic development and can promote the coordinated development of the two systems. The regression coefficients for the western and northeastern regions are 0.0829 and 0.0961, respectively, which did not pass the significance test, indicating that the economic development promotion effect of the western and northeastern regions is not significant, and the level of social and economic development needs to be improved.

Train stands for highway mileage and is a manifestation of traffic accessibility. On the one hand, the increase in traffic network density can provide convenient conditions for the flow of medical resources and residents' medical treatment. According to Table 7, in the whole country, the coefficient of determination of transportation infrastructure was 0.00812, which failed the significance test, and the level of transportation infrastructure construction has no positive effect on the promotion of the two systems. The coefficient of determination of the eastern regions was 0.148, and it passes the significance test of 5%, indicating that it has a promoting effect on the integration and development of the two systems in the eastern regions. In the eastern regions, the terrain is relatively flat, the traffic density is relatively high, the population density is comparatively high, and the relative availability of medical resources is also relatively high. However, the promotion effect of Train in the central and western regions is not obvious; the determinable coefficients of highway density

in the central and western regions are 0.00722 and 0.00434. The western region is sparsely populated, the terrain is large, the economic foundation is weak, its road density is low, and the accessibility of medical resources is poor. The determinable coefficient of highway density in Northeast China is −0.881, and through a significance test of 5%, it indicates that the transportation infrastructure in Northeast China has a significant inhibitory effect on the coordinated development of the two systems. This is mainly due to the vast territory and sparse population in Northeast China, where the overall highway passenger transportation in the three provinces of Northeast China is in a weakly connected state. The Chinese government also needs to strengthen the construction of transportation infrastructure in the central and western regions and do a good job of spatial planning of medical service institutions to provide a more convenient medical treatment pattern for the masses.

Pdr population mortality is a negative indicator. The representative of health, in a certain number of years, the population mortality rate has decreased steadily, indicating that the living standards of the region have gradually improved, and the health level has been promoted. According to Table 7, from the perspective of the whole country, the mortality rate has a certain negative effect on the coordination degree of the two systems; the determinable coefficient of population mortality rate is −0.107 and has passed the significance test of 1%, indicating that the overall health level of China needs to be improved. This negative impact is not significant in the central and northeastern regions but is more pronounced in the western regions. The determinability coefficient for the eastern region is 0.0055, which did not pass the significance test, indicating a relatively high level of healthy development in the eastern region. However, the determinability coefficients for the central and northeastern regions were −0.0129 and −0.0357, both of which did not pass the significance test, indicating that the health level of the central and northeastern regions has an insignificant inhibitory effect on the coordinated development of the two systems. However, the determinability coefficient in the western region is −0.0981, and through a 10% significance test, it indicates that the health level in the western region has a significant inhibitory effect on the coordinated development of the two systems. The central, northeastern, and western regions should focus on improving their health levels and enhancing the fairness and accessibility of medical resources.

Indu industrial structure, the optimization of industrial structure plays an important role in promoting traditional Chinese medicine medical services and economic development. According to Table 7, the determination coefficients of industrial structure for China, central, western, and northeastern regions are 0.0085, 0.0171, 0.00186, and 0.00185, respectively, all of which have not passed the significance test. This indicates that the industrial structure has no significant promoting effect on the overall coupling and coordination between traditional Chinese medicine medical services and the economy in China. The determinability coefficient of the eastern region is 0.011, and through a 10% significance test, it indicates that the industrial structure in eastern China is excellent, which has a significant positive promoting effect on the coordinated development of the two systems in the eastern region. The central, western, and northeast regions also need to increase the development of the tertiary industry, constantly optimize the industrial structures, and enhance the positive role of the industrial structures in promoting the coordinated development of the two systems.

5 Suggestions and conclusions

5.1 Suggestions

To promote the coordinated development of traditional Chinese medicine medical treatment and social economy, it is necessary to pay attention to regional individuality based on integrity. Fully consider the regional differences of east, central, west and northeast, focusing on the improvement of quality. Form a situation of cross-regional assistance and strive to build a pattern of eastern regions helping the northeast, supporting the central region, and driving the western region.

The eastern region needs to change its resistance in terms of human capital in traditional Chinese medicine healthcare. The human capital of traditional Chinese medicine (TCM) needs to be optimized in both quantity and quality, with a reasonable allocation of TCM medical service personnel to prevent the siphoning effect of central cities on TCM medical talents and to break down the hindering role of TCM medical human capital. We need to improve the population distribution density, facilitate the two-way referral system, alleviate the excessive concentration of traditional Chinese medicine medical resources, promote resource sinking, dilute the siphoning effect, and thereby improve the utilization rate of medical and health resources, thereby enhancing the health level of the eastern region.

The human capital, transportation infrastructure and industrial structures of traditional Chinese medicine in the central region need to be improved. To maintain the strategy of the rise of central China, it is necessary to increase the support of medical and health facilities and improve the technical level of health technicians. We must improve the quality of transportation infrastructure construction in the central region and promote the transformation and upgrading of the industrial structures. The central region should actively improve the investment environment, attract high-tech talents, adjust the economic structure, and promote the transformation and upgrading of the industrial structure (48).

The western region needs to find the advantages of two systems based on resource and policy advantages. It is necessary to improve the level of economic development, strengthen the construction of transportation infrastructure, promote the introduction of medical and health talents, optimize the salary and job development structures in remote mountainous areas, and introduce more talent. By leveraging the government's policy support and fiscal orientation toward traditional Chinese medicine and economic development, we aim to enhance the level of economic development in the western region. Economically underdeveloped areas should optimize the salary and job development structure in remote mountainous areas and introduce more talent. Pay attention to the rational planning of transportation and population, and improve the accessibility of medical resources. They are actively introducing resources for industrial innovation in the eastern and central regions, enhancing their radiation and driving role in

the western region, and playing a fundamental role in economic development and industrial upgrading.

The Northeast region needs to focus on improving the positive role of traditional Chinese medicine human capital, traditional Chinese medicine medical finance and population density in the coupling coordination degree of the two systems. Stimulate the internal driving force of economic development, strengthen the policy of "attracting the phoenix and returning the nest", and ensure the return of their labor force. Raise the fertility rate of the population in northeast China and ease the degree of aging. We should increase investment in medical finance and improve the service capacity and level of traditional Chinese medicine. Continue to optimize the industrial structure, ensure the development strength of the primary and secondary industries, expand the competitive advantage of the tertiary industry, accelerate the transformation and upgrading of the secondary industry structure, extend the regional industrial chain, and stimulate the endogenous driving force of economic development.

Finally, for developing countries with unbalanced economic and medical development, governments need to formulate development policies according to local conditions. For places with stable economies, we should pay attention to maintaining their long-term growth momentum. Strengthen interregional technical cooperation in healthcare. Medical specialist alliances should be promoted among neighboring regions to promote the sinking of high-quality medical and health resources (49). More policy support must be given to less developed areas to help the strong overcome the weak and achieve common development. The reasonable planning of traffic and population in remote areas should pay attention to the accessibility of medical resources. Clarify one's own strengths and development weaknesses, and implement policies due to shortcomings. Provinces with high coupling and coordination should actively explore the path of high-level coordinated development between traditional Chinese medicine and the regional economy while maintaining their own advantages. Provinces with low coupling scheduling should clarify their own development shortcomings and characteristics, find breakthroughs in collaborative development, build a distinctive traditional Chinese medicine service system, actively seek cooperation with regions with high-coupling coordination, and focus on promoting the coupling coordination degree of each region from "competitive relationship" to "collaborative effect".

5.2 Conclusion

(1) During the study period, the development level of traditional Chinese medicine medical treatment was superior to that of social and economic development, and the overall economic development was lagging behind, but the development gap between the two systems was gradually narrowing. The eastern and northeastern regions are developing synchronously, and the level of traditional Chinese medicine medical services in the central and western regions is higher than the level of economic development.

(2) The coordination degree between traditional Chinese medicine medical treatment and the social economy was mainly focused on the transitional coordination type and gradually increased steadily, but there are evident differences among different regions. The coupling coordination degree showed the development pattern of east > middle > west > northeast. The spatial agglomeration of the coupling coordination degree of the two systems in China presented a positive correlation, and the agglomeration degree was strengthened year by year.

(3) The level of economic development is the most critical factor affecting the coupling and coordination degrees of the two systems; however, there is still a need to strengthen human capital and health levels in traditional Chinese medicine. The eastern region needs to optimize the structure of traditional Chinese medicine medical human resources. The central and western regions focus on improving the level of healthy development, while the northeast region focuses on improving the level of transportation infrastructure and health. Developing countries with significant differences in coupling and coordination development should strengthen their own advantages and actively engage in mutual learning and cooperation with other high-coupling regions, strengthening cooperation and collaborative development within and outside urban agglomerations.

6 Limitations

On the one hand, there is currently no complete and scientific comprehensive evaluation index system for traditional Chinese medicine medical services and economic development in China, so there may be shortcomings in establishing an index system when selecting indicators in this article. The statistical data foundation related to traditional Chinese medicine medical services is weak, so this article conducts research at the provincial level in China. On the other hand, there are certain shortcomings in the selection of influencing factors in this article. Only the relatively basic influencing factors were selected, so the selection of influencing factors is not comprehensive enough. In future, based on a more complete and scientific indicator system, we will conduct in-depth research on the coordinated development of traditional Chinese medicine medical services and regional economy in various cities or urban areas of a province, making the research more in-depth and the research strategies more practical and feasible.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

HL: Data curation, Software, Writing – original draft, Conceptualization. ZJ: Data curation, Investigation, Writing – review & editing. JD: Data curation, Investigation, Writing – review

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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Practical quality improvement changes for a low-resourced pediatric unit

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Background: This work describes a sustainable and replicable initiative to optimize multi-disciplinary care and uptake of clinical best practices for patients in a pediatric intensive care unit in Low/Middle Income Countries and to understand the various factors that may play a role in the reduction in child mortality seen after implementation of the Quality Improvement Initiative.

Methods: This was a longitudinal assessment of a quality improvement program with the primary outcome of intubated pediatric patient mortality. The program was assessed 36 months following implementation of the quality improvement intervention using a *t*-test with linear regression to control for co-variates. An Impact Pathway model was developed to describe potential pathways for improvement, and context was added with an exploratory analysis of adoption of the intervention and locally initiated interventions.

Results: 147 patients were included in the sustainability cohort. Comparing the initial post-implementation cohort to the sustainability cohort, the overall PICU unexpected extubations per 100 days mechanical ventilation decreased significantly from baseline (6.98) to the first year post intervention (3.52; $p < 0.008$) but plateaued without further significant decrease in the final cohort (3.0; $p = 0.73$), whereas the mortality decreased from 22.4 (std 0.42) to 9.5% (std 0.29): p value: 0.002 (confidence intervals: 0.05;0.21). The regression model that examined age, sex, diagnosis and severity of illness (via aggregate Pediatric Risk of Mortality (PRISM) scores between epochs) yielded an adjusted R-squared (adjusting for the number of predictors) value of 0.046, indicating that approximately 4.6% of the variance in mortality was explained by the predictors included in the model. The overall significance of the regression model was supported by an F-statistic of 3.198 ($p = 0.00828$). age, weight, diagnosis, and severity of illness. 15 new and locally driven quality practices were observed in the PICU compared to the initial post-implementation time period. The Impact Pathway model suggested multiple unique potential pathways connecting the improved patient outcomes with the intervention components.

Conclusion: Sustained improvements were seen in the care of intubated pediatric patients. While some of this improvement may be attributable to the intervention, it appears likely that the change is multifactorial, as evidenced by a significant number of new quality improvement projects initiated by the local clinical team. Although currently limited by available data, the use of Driver Diagram and Impact Pathway models demonstrates several proposed causal pathways and holds potential for further elucidating the complex dynamics underlying such improvements.

KEYWORDS

quality improvement, pediatric intensive care unit, low/middle income country, unplanned extubations, Mass General Brigham, institutional review

Introduction

The United Nations' Sustainable Development Goal is to reduce mortality under five years of age to fewer than 25 lives per 1,000 (2.5%) by 2030 (1). Settings characterized by elevated mortality rates within low and middle-income countries (LMIC) represent optimal targets for intervention, as the relatively high number of cases presents the most substantial opportunity for impact. One such setting is pediatric intensive care units (PICUs) in these countries, which often see mortality rates ten times higher than those in high-income countries (25–50% vs. 2–5%) (2–5). Intubated children are at particularly high risk. Data collected from one PICU in a LMIC Latin American country, found all-cause PICU mortality in intubated patients to be 24%, with an unplanned extubation (UE) rate of 31%, compared to a rate of approximately 2% in the United States (6). Unplanned extubation involves the unplanned and unintentional dislodgement of an endotracheal tube and contributes to significant morbidity, including hypoventilation, hypoxia, ventilator-associated pneumonia, prolonged mechanical ventilation, acquired subglottic stenosis, hemodynamic collapse, and death (7, 8).

Operation Airway is a surgical mission-based nonprofit organization of Massachusetts Eye and Ear (MEE) and is composed of pediatric providers from MEE and Massachusetts General Hospital, both teaching hospitals of Harvard Medical School. Careways Collaborative was born from Operation Airway and is a nonprofit organization that designs, disseminates, and studies educational programs and QI interventions aimed at reducing pediatric mortality in LMICs. In 2017, Careways Collaborative partnered with Hospital Nacional de Niños Benjamín Bloom, the largest public children's hospital in El Salvador, to develop and deploy a QI protocol, wherein a multidisciplinary, video-based educational curriculum is provided to PICU staff with a goal of optimizing safe care of intubated patient and thereby reducing PICU mortality.

To evaluate and iteratively improve the QI protocol, we collected pre-intervention data for 18 months (Epoch 1), then implemented the initial educational intervention and tracked PICU airway-related morbidity and mortality for three months (Epoch 2). We observed a significant decrease in unplanned extubations/100 days Mechanical Ventilation (UE/MV) (6.98 to 3.52) and pediatric intensive care unit (PICU) mortality (26·7 to 22·4%) between Epoch 1 and 2 (9). Following Epoch 2, there was a 36-month period with no in-person mission trips from Careways due to the COVID-19 pandemic. When mission trips resumed in January 2023, we had an opportunity to assess longer-term impacts of the QI program. This Quality Report describes findings from Epoch 3, including how local health teams adapted the QI protocols over time to meet local needs and reports on the sustained impacts of the protocol.

Abbreviations: QI, Quality improvement; PICU, Pediatric intensive care unit; LMIC, Low/middle income country; UE, Unplanned extubations; MGB, Mass General Brigham; IRB, Institutional review board.

Materials and methods

Intervention design and background

Hospital Nacional de Niños Benjamín Bloom is the largest public children's hospital in El Salvador. It is the only academic, stand-alone children's hospital in El Salvador and it cares for some of the most disadvantaged children in the country and patients with the most complex medical needs. It is a mixed medical surgical unit with 16 beds, staffed during the day by a pediatric resident and PICU fellow with a pediatric intensivist on site part-time; there is one on-site respiratory therapist at all times; and the nursing ratio is 1:4. Available monitoring includes pulse oximetry, respiratory rate, non-invasive blood pressure, telemetry, central venous pressure, and arterial pressure. Available supportive technologies include hemodialysis and mechanical ventilation.

During a mission trip to Hospital Nacional de Niños Benjamín Bloom in 2017, Operation Airways (OA) and hospital staff developed a longitudinal database to count airway related morbidity and mortality in the PICU (10). In parallel, we identified knowledge gaps and communication failures possibly contributing to unplanned extubations and other adverse events. In response, we designed the initial educational intervention and QI protocols outlined below, aiming to: (1) enhance the knowledge of every member within the care team; (2) foster collaboration and improve communication among team members; and (3) cultivate a safety-oriented culture wherein team members approach each case systematically, ultimately minimizing preventable errors and expediting issue identification.

The overall QI implementation and project timeline is shown in Figure 1. Epoch 1 began with 18 months of collecting pre-intervention data, after which we implemented the initial QI and educational

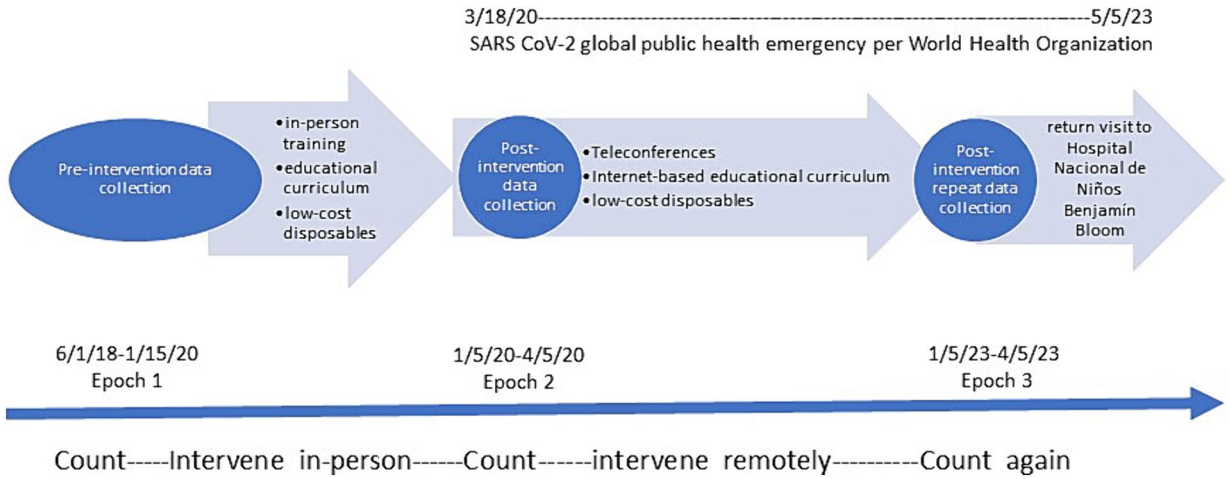


FIGURE 1
Timeline of pre-post intervention study. Timepoint 0 indicates start of 18-month pre-intervention period of data collection. Timepoint 1 indicates implementation of multi-media, in-person education-based intervention. Timepoint 2 when short-term post-intervention data collection period occurred. Timepoint 3 indicates 18-month period when no research staff visited the Bloom Hospital and relied on light-touch, internet-based support of the Bloom Hospital PICU team. Timepoint 4 indicates repeat post-intervention data collection during the same season as Timepoint 2. Timepoint 5 indicates return visit to the Bloom Hospital 18 months later.

intervention. Post-implementation data was then collected for three months (January through April) (Epoch 2) (9). Findings from this initial pre-post intervention study has been published elsewhere (9). Data, including demographics, illness severity scores, child age and weight, incidence of unexplained events, severity of illness (utilizing the Pediatric Risk of Mortality (PRISM) severity of illness instrument) (11–13), and mortality were recorded by a dedicated bilingual respiratory therapist with periodic audits by two independent reviewers to ensure accuracy (these two audits were performed by chart review by two local physicians who were not part of the primary research team). The study was not considered human subjects research by the guidelines of the Mass General Brigham (MGB) and Hospital Nacional de Niños Benjamín Bloom Institutional Review Board's (IRB).

Following Epoch 2, there was a 36-month period with no data collection due to the COVID-19 pandemic. During this period, the local multidisciplinary surgical and PICU teams continued to have access to the internet-based educational curriculum, including a series of brief video-based tutorials and demonstrations covering topics such as how to safely turn the intubated patient, how to select appropriately sized ETTs, and how to monitor safe ETT cuff pressure. Once mission trips resumed, we resumed data collection on PICU morbidity and mortality data for 3 months, from January to April, 2023 (Epoch 3). The choice of the three months mirrored those months where data was collected for Epoch 2 and to account for any seasonal variation. Data collection in Epoch 3 was performed by the same dedicated bilingual respiratory therapist trained during the initial implementation, with audits performed by an independent reviewer for accuracy. The OA mission team also collected qualitative observational data on the presence or absence of the QI intervention components that had been previously implemented as well as any new QI interventions undertaken by the local team (Table 1). These local based QI interventions were developed by the local PICU team using the Quality Improvement framework they had learned previously specific but now expanded to include daily discussions and review of non airway factors such as dentition and nutrition, to reconfigure the PIVU space to allow for better ventilation and easier access for the nurses to provide care, to include routing periodic simulation as part of their team training.

Intervention

The intervention entails the implementation of the Careways QI protocol, which (1) provides multidisciplinary, video-based educational curriculum to PICU staff; (2) models multidisciplinary team rounding; (3) provides on-line readings and video modules accessible via QR codes posted across the PICU. The internet-based educational curriculum includes a series of brief video-based tutorials and demonstrations with new installations added over time covering topics such as how to safely turn the intubated patient, how to select the appropriately sized ETT, and how to monitor safe ETT cuff pressure. Figure 2 provides an example of a QR code that links to a Spanish-language video on how to properly secure an ETT.

Driver diagram

Driver diagrams are designed to elucidate the logical links between aspects of the environment, culture, and workflows of an institution with the outcomes that a team is trying to change in a QI project. Primary drivers are directly linked to the overall outcome, while secondary drivers primarily influence these primary drivers. Tertiary drivers have a more direct relationship with secondary drivers, and so forth. Understanding drivers provides targets for interventional strategies to improve the outcome of interest. We designed a driver diagram to describe pediatric mortality in the PICU through discussion with a multidisciplinary team of OA members and local clinicians (Figure 3). The model was iteratively refined with the assistance of a QI expert until the team felt that consensus was reached.

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TABLE 1 Observed pragmatic, practical changes made by the local health care team and observed in the Bloom Hospital PICU June 2022.

Element	Careways driven Education-based intervention	Careways driven Observed Epoch 2	Locally driven Observed Epoch 3
Implementation of daily ventilator associated pneumonia prevention bundle			
Head of bed elevated 30 degrees	✓	✓	✓
Daily oral hygiene			✓
Daily team discussion regarding extubation readiness	✓	✓	✓
Addition of a dentist to the PICU team to evaluate/treat patients with poor dentition			✓
Early initiation of enteral nutrition			✓
Consideration for early trachostomy placement in patients with expected lengthy need for invasive ventilation			✓
Increased use of cuffed endotracheal tubes (ETTs)	✓	✓	✓
Creation of a reference chart for proper sizing of cuffed ETTs	✓	✓	✓
Daily assessment of cuff leak to prevent over- or under-inflation	✓	✓	✓
Emergency card at patient's head of bed including:			
Name			✓
Diagnosis			✓
Weight			✓
Lines			✓
ETT size			✓
Calculated code dose of epinephrine			✓
Multidisciplinary huddle at 6 AM with charge nurse, bedside nurse, respiratory therapist, intensivist and surgeon	✓	✓	✓
Formalization of pediatric critical care medicine fellowship			✓
Improved sedation with adoption of dexmedetomidine as mainstay of therapy			✓
Use of non-invasive ventilation to enable earlier extubation			✓
Increased use of standardized securement methods for orotracheal and nasotracheal ETTs	✓	✓	✓
Expansion of PICU floor plan allowing for more spacing between patient beds for easier access for nursing care.			✓
Initiation of an in-house simulation-based educational program for multidisciplinary PICU team	✓	✓	✓

A number of unanticipated practice changes not formally included in the education-based intervention were noted by the research team upon their return to the Bloom Hospital 18 months after their last visit. Some changes reflected formalization of practices modeled by the research team such as placement of an emergency card at the head of each ICU bed, while others were completely new initiatives like increasing the space between ICU beds to address infection control concerns.

Impact Pathway Model

Driver diagrams and Impact Pathways are closely related as they both serve to delineate the causal relationships between interventions, intermediate outcomes, and ultimate goals. They can both serve to suggest process metrics and future data collection strategies for understanding the exact impact of an intervention. Driver diagrams focus more broadly on describing the system, which can be useful for considering targets for interventions, while impact pathways can help clearly describe how an intervention is impacting the outcome of interest. Using the same methods as for the driver diagram, we developed an Impact Pathway Model (Figure 4) to comprehend and monitor changes to the causal pathway that we believe will lead to the desired outcomes. We began with the four components of the intervention and sought as a group to connect those to the outcome of interest.

Analysis and findings

Data

An analytic data file for PICU patients, under 18 years of age, undergoing mechanical ventilation was constructed. The data file includes binary variables for gender, intubation status, accidental intubation, and mortality. The dataset also includes date of intubation, age, and weight, PRISM severity of illness scores, and diagnosis. Data were cleaned to remove duplicate entries, diagnosis codes were consolidated into 4 collapsed categories for improved clarity, and binary variables (e.g., accidental extubation) with values greater than 1 were set to 1, e.g., multiple AEs were reset to binary yes/no was the member AE. Missing data was treated as missing, i.e., not imputed.

147 patients met eligibility criteria in Epoch 3. There was no missing outcome data. 45·5% were female. The mean age was 3·2 years and the mean weight was 18·16 kg. The most common diagnosis was sepsis (38·9%) followed by pneumonia (35·8%) and trauma (7·0%). Epoch 2 had 98 patients, and Epoch 3 had 147 patients. The groups were similar regarding age, sex, weight, severity of illness (PRISM scores), and diagnosis (Table 2). The Pediatric Risk of Mortality (PRISM) score was developed from the Physiologic Stability Index (PSI) to reduce the number of physiologic variables required for pediatric ICU (PICU) mortality risk assessment and to obtain an objective weighting of the remaining variables (12, 13).

Given the hypothesis that PICU mortality in low/middle resources countries is unusually high relative to higher resourced settings due to avoidable errors, our group felt that a 15% or greater diminishment of all cause child mortality following our education and culture change intervention was achievable and would be clinically meaningful. Assuming a Power of 0·8 and alpha of 0·05, we needed 87 children in Epoch 3. The final sample included 98 patients from Epoch 2 and 147 patients in Epoch 3.

Analysis

The primary outcome was all cause mortality in intubated PICU patients in Epoch 2 compared to Epoch 3, to assess for sustainment of the improvements noted in the earlier study. Secondary analyses consisted of comparisons between proportions of unexpected events/100 days mechanical ventilation. This was assessed using an independent *t*-tests for differences in means, 2-sample test for equality of proportions with continuity correction, and linear regression to account for covariates, including age, sex, PRISM severity of illness scores, and admitting diagnosis. As an exploratory measure, we also report the list of sustained QI practices and new practice changes observed in Epoch 3.

Comparing Epoch 2 to Epoch 3, the overall PICU mortality decreased from 22.4 (std 0.42) to 9.5% (std 0.29): p value: 0.002 (confidence intervals: 0.05;0.21). The observed significant decrease in mortality persisted even after controlling for age, weight, PRISM severity of illness scores, and initial diagnoses. The regression model yielded an adjusted R-squared of 0.046, indicating that approximately 4.6% of the variance in mortality was explained by the predictors (F-statistic: 3.198; $p = 0.008$).

Secondary outcomes

Comparing Epoch 2 to Epoch 3, the unexpected events per 100 days of mechanical ventilation did not significant change 3.52 to 3.30; p value: 0.29 (confidence intervals: −0.10;0.30) (2-sample test for equality of proportions with continuity correction).

Qualitative observations

Observational data was notable for sustainment of the QI practices implemented prior to Epoch 2 and additional locally driven QI measures. The modified pragmatic QI program the local team developed to promote and ensure communication and multi-disciplinary care planning was utilized in all 147 patients seen in the PICU during this time period. Table 1 details the additional unanticipated practice changes implemented by the local health care team.

System modeling

The driver diagram and impact map are shown in Figures 3, 4, respectively. In the impact diagram, each component contributes to, but is not uniquely responsible for, reducing interruptions, reducing errors, reducing PICU staff turnover, and thereby reducing PICU mortality. Both of these diagrams can provide potential process metrics to validate the underlying logic linking the interventions to the outcomes. The driver diagram can additionally provide potential targets for additional interventions to further improve PICU mortality.

Discussion

We observed sustained local improvement in this QI project with continued decreases in PICU mortality in intubated pediatric patients 36 months following implementation of an educational and QI intervention aimed at increasing multidisciplinary teamwork and decreasing airway related morbidity and mortality. Interestingly, the qualitative observations showed a significant number of locally initiated QI projects in addition to our initial QI intervention.

We believe these changes indicate a burgeoning PICU safety culture and may help to explain why the decrease in mortality from Epoch 1 to Epoch 2 was not only sustained but continued to improve in Epoch 3 from 22·4% to 9·5%.

It is of interest that secondary measures/ adverse events such as UEs changed significantly between Epochs 1 and 2 (9), but not between Epochs 2 and 3, whereas mortality continued to significantly drop between Epochs 1, 2, and 3. It may be that AE drops immediately to the lowest possible level (or lowest reasonable level without added intervention) and remained stable thereafter, and that subsequent mortality decreases were due to (a) other components of the intervention bundle, (b) changes in the severity of cases, (c) exogenous effects, or (d) a combination of these three. Going forward, systematic collection of data related to elements in the Impact Pathway will enable us to tease apart these connections and form a more refined understanding of the causal connections.

Many global health studies have demonstrated short-term favorable impacts on patient care immediately following implementation of QI processes in low-resource settings (14, 15), and some have reported on long-term sustainability of process improvement, retention of provider skills and strengthening of partnerships between teams in high and low-resource settings (16, 17). Yet few global health investigators have demonstrated long-term effectiveness of QI programs in LMIC on patient outcomes, often citing lack of robust data systems to reliably measure morbidity and mortality and attrition of provider skills without ongoing training (18, 19). While we acknowledge that our intervention alone may not account for the sustained improvement observed in this study, we believe that our Driver Map and Impact Pathway models, combined with forthcoming additional data collection and a comprehensive analysis will address significant gaps in understanding the relationships and long-term impacts of these programs, contributing to the broader context of global health studies demonstrating both short-term improvements and long-term sustainability in low-resource settings.

FIGURE 2
QR code for Spanish-Language Educational Video. Example of one of many QR codes posted in the PICU linking providers to 2–4 min Spanish-language instructional videos addressing safe airway management procedures and practices such as proper securement of the ETT, proper ETT selection, safe suctioning practices and safe management of cuff pressure in cuffed ETTs.

Study strengths and limitations of the analysis

One key strength of our analysis was the use of a reliable database to accurately measure the impact of our intervention on patient outcomes (18, 19). Our research group attempted to account for possible confounders that might influence our findings related to a decrease in child mortality. Data was collected for a similar amount of time and during a similar season of the year to account for possible seasonal variation of disease in EL Salvador. Choosing a similar season was not planned in advance (because no one foresaw covid) but was considered while planning post covid trips as a deliberate choice made

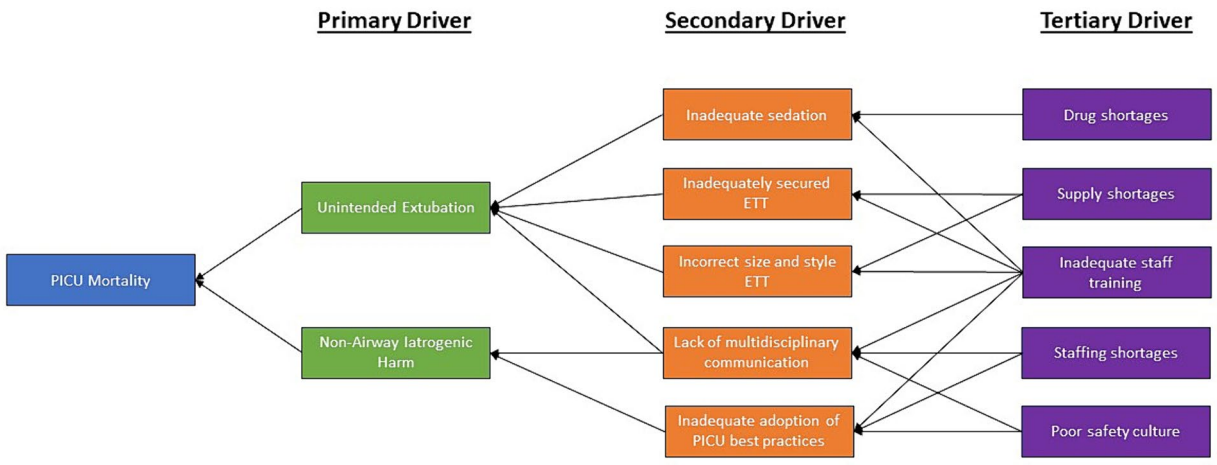


FIGURE 3
Careways Impact Pathway Model. The Careways Impact Pathway Model elucidates the pathways through which the planned Quality Improvements intervention attains its specified objectives, delineates the causal mechanisms by which the intervention operates, as well as demonstrates the interconnectedness and mutual reinforcement among its constituent elements. Within this framework, balancing factors are elements that might counteract or moderate the effects of the intervention, helping to maintain equilibrium within the system.

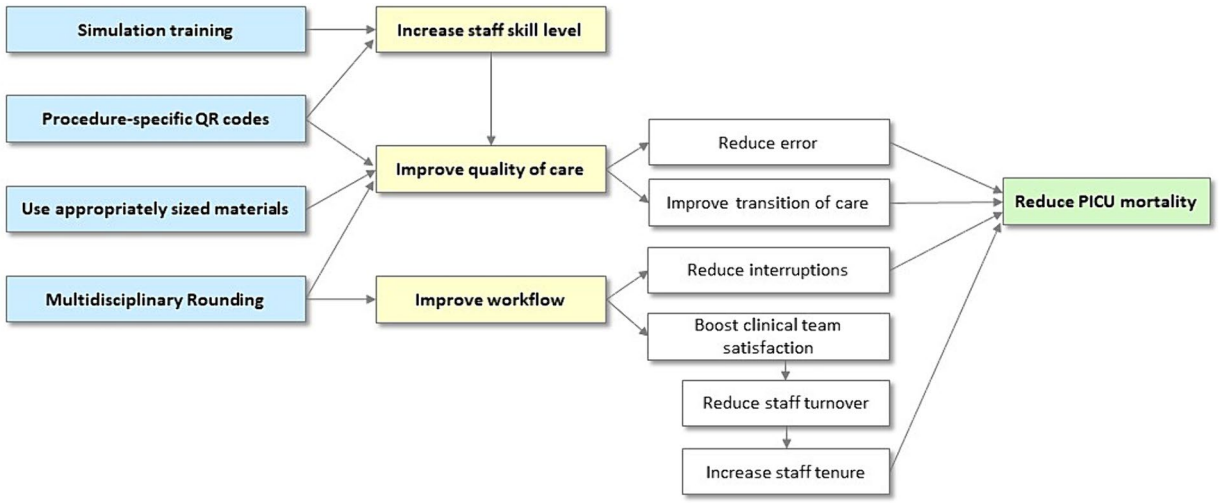


FIGURE 4
Impact Pathway Model used to comprehend and monitor changes to the causal pathway that we believe will lead to the desired outcomes.

TABLE 2 Demographics.

	Epoch 2 (*N* = 98)	Epoch 3 (*N* = 147)	*p* value
Female sex – *n* (%)	55 (45·9)	57 (45·5)	0.22
Age in years – mean (SD)	2·9 (3·99)	3·2 (3·2)	0.55
Weight in kg – mean (SD)	14·13 (16·83)	18·16 (15·64)	0.06
Diagnosis			
Sepsis – *n* (%)	39 (39·8)	58 (38·9)	0.24
Pneumonia – *n* (%)	35 (35·6)	32 (35·8)	
Trauma – *n* (%)	9 (9·2)	37 (7·0)	
Other – *n* (%)*	15 (15·3)	20 (18·3)	
PRISM Severity Score (SD)	16.61 (8.08)	16.59 (6.95)	0.06

Comparison of patient demographics between the immediate post-intervention cohort and the long-term post-intervention cohort indicate no difference in sex or weight, though patients in the long-term post-intervention cohort were slightly older with more trauma and "other" diagnoses than in the short-term post-intervention cohort. There were more than ten different diagnostic possibilities in the long-term post-intervention cohort such that the top three are listed followed by "other" which includes meningitis, Guillain-Barré, metabolic, cardiac, seizures, and other infections. Diagnosis did not significantly impact mortality either when utilizing the "other" category to describe the remaining seven diagnoses or when all categories were evaluated by logistic regression analysis. *Other diagnoses include meningitis, Guillain-Barré, metabolic, cardiac and seizures. **Epoch 1 data other than PRISM severity scores have been reported previously. The PRISM severity score for Epoch1 was 16.35 and was neither significantly different that the PRISM score for Epoch 2 or 3.

to help address/control for exogenous seasonal/country-level effects. Age, sex, PRISM severity of illness indices, and diagnosis were identified as possible factors underlying severity of illness and accounted for (age and diagnosis were specifically accounted for by regression analysis post-hoc as there were imbalances in these seen in Table 2).

We make no claims that our intervention alone led to the sustained, and continued, improvement observed in this study. Rather, our observational data and proposed Impact Pathway model suggest that the improvement is multifactorial and complex. Future research is underway to collect quantitative data to validate the Impact Pathway model and understand the impact of the various QI programs now at this site. This work will increase our understanding of the system to promote future improvement.

Future directions

The low-cost nature of our initial intervention and its sustainable impact with only light-touch, internet-based support suggests the opportunity for scalability in the future. We aim to roll out this intervention in three additional PICUs in other LMIC countries in Central and South America to better understand how this intervention is locally adapted, what needs to be taken into account for future scalability of the intervention, and whether this impressive improvement in mortality can be recreated elsewhere. This future work will generate additional data which will be used to refine and validate the Impact Pathway model, furthering our understanding of how improvements occur in LMIC PICUs. Although a direct causal relationship between the adoption of this QI improvement program and reduction in child mortality may be difficult to prove, we hope to see a mirroring of this significant decrease in child mortality in these next three countries' PICUs post-intervention as well. Our chief goal will be to work further to optimize these forms of sustainable quality improvement programs focusing on enhanced communication and multidisciplinary care.

Conclusion

Overall, we present data showing a sustained improvement in reduction of mortality in intubated PICU patients following a low-cost, low-touch educational and QI intervention aimed at improving multidisciplinary care and uptake of clinical best practices. A direct causal relationship between the implementation of this intervention and

reduction in child mortality remains difficult to prove. However, we propose an Impact Pathway model positing potential causal pathways based on our observations of the intervention implementation and the addition of other QI interventions undertaken by the local team following the initial intervention. Work is underway to enhance the implementation of the intervention across a wider range of settings and gather comprehensive data on its functional components and their association with patient outcomes. We eagerly anticipate advancing this work to cultivate a replicable and sustainable model for Quality Improvement programs across low-resource countries, transcending the confines of a PICU and extending to operating rooms, wards, and every facet of a child's journey from home to hospital and back home again.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were exempted for consideration as research by the Massachusetts General Hospital's Institutional Review Board as they were considered Quality Improvement studies. The studies were conducted in accordance with the local legislation and institutional requirements and were formally approved by the Benjamin Bloom Hospital Institutional Review Board, the local hospital where the work was being done. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because this was aggregate data and no PHI was recorded and the study was a QI study.

Author contributions

PY: Writing – review & editing, Writing – original draft. KC: Writing – review & editing, Writing – original draft. AS-W: Writing – review & editing, Writing – original draft. JB: Writing – review & editing, Writing – original draft. LF: Writing – review & editing, Writing – original draft. SH: Writing – review & editing, Writing – original draft. AR: Writing – review & editing, Writing – original draft. AC: Writing – review & editing, Writing – original draft, Project administration. AN: Writing – review & editing, Writing – original draft. AJ: Writing – review & editing, Writing – original draft. EZ: Writing – review & editing, Writing – original draft. CH: Writing – review & editing, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Will urban scale affect health services inequity? The empirical evidence from cities in China

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Background: The equity of public resources triggered by city shrinkage is a global challenge. Significantly, the impact of city shrinkage on the allocation of health service resources needs to be better understood. This study explores the impact of population change on government investment and health service delivery in shrinking cities.

Data and method: Using data from China's Urban Statistical Yearbook (2010–2020), we employ regression discontinuity (RD) and fixed-effect models to examine the causal relationship between city shrinkage and health service provision.

Result: Shrinking cities show significant disparities in health resources, particularly in bed numbers (–1,167.58, $p < 0.05$) and doctor availability (–538.54, $p < 0.05$). Economic development ($p < 0.01$) and financial autonomy ($p < 0.01$) influence hospital bed distribution. Investments in public services (primary schools and teachers, $p < 0.01$) affect health resource delivery. Robustness tests support our results.

Conclusion: This study reveals how city shrinkage disrupts health service provision and equity, establishing a causal relationship between city shrinkage/expansion and health resource allocation, emphasizing the imbalance caused by urban population changes. City expansion intensifies competition for health resources, while shrinking cities struggle to provide adequate resources due to government reluctance. Policymakers should adapt health resource allocation strategies to meet patient demands in changing urban landscapes.

KEYWORDS

city shrinkage, health service, equity, resource allocation, population change

1 Introduction

The demographic change poses public service challenges, as various factors associated with urbanization, such as demographic changes, socio-economic disparities (1), and regional development imbalances, may significantly impact and require careful allocation of health resources (2, 3). Several studies indicated that population decline indirectly results in the unsustainable maintenance and operation of urban infrastructure, ultimately reducing the

quality of urban amenities (4). Modern cities compete for health services and city development, providing opportunities for health advances in city development. If competition aims to increase productivity, it may exacerbate the unequal distribution of health service resources between cities, and the country or region will face significant health service disparities (5). In addition, with the acceleration of urbanization, the demand for residents' medical and health services has been released to a greater extent (6). However, the difference in urbanization may also lead to a gap in healthcare services.

Some studies have focused on the relationship between city population and the demand for and delivery of public service resources. Areas with high urbanization and population levels tend to have poorer ecological environments, negatively impacting the population's health (7). Patient mobility leads to changes in the spatial economy of health services, resulting in the imbalanced allocation of medical service resources (8). Therefore, population dynamics, including population growth and loss, can impact public service delivery in a city. Population loss is considered an essential determinant of city shrinkage, a significant issue in city development referring to a decrease in city population or reduction in population density. Several factors contribute to city shrinkage, including suburbanization, disasters, an aging population, low fertility rates, etc. (9, 10).

Population decline can lead to reduced fiscal revenue, idle and wasted public service facilities, and impact the accessibility of services for residents. Many developed countries face this problem. For example, South Korea has experienced increased housing vacancy rates in city centers due to city shrinkage (11). In 1975, New York City faced a fiscal crisis attributed to population decline, economic factors, and political challenges; however, the government's fiscal cuts primarily affected public services in impoverished areas of the city, including fire facilities, leading to severe fires in slum areas, exacerbating the plight of the underprivileged population (12). Researchers found that this policy resulted in a continuous deterioration of health conditions among vulnerable groups over the next 20 years (13). In many cases, city shrinkage affects residents in different areas differently, as various service reductions, including in health services, affect resource allocation fairness. However, policies can be implemented to improve the situation and ensure that those with greater needs can access a greater share of health services (14).

The issue of equity between different areas is difficult to deal with, but there are ways to mitigate the problem of city shrinkage so that it does not affect all groups. Some cities have counteracted this trend through industrial transformation and upgrading (15). Some have increased public services or health expenditures to improve health equity (16, 17). Health resource allocation is essential to effective city management and meeting the challenges of city shrinkage (18). Some studies suggested that urban–rural medical disparities be balanced to improve service quality and reduce cross-regional health services (19). Therefore, there is a need to rationalize resource allocation with a city's population dynamics (20).

Our study explores the impact of city shrinkage on health service provision and contributes to the field in several new ways. First, it is concerned with allocating resources for health services in the context of shrinking cities. Despite its importance in city development, this area has not yet received much research attention. Second, it examines the role of the population in government decisions about health services delivery. Shrinkage cities with declining populations may also be urbanizing (21). Moreover, our research focuses on cities in developing countries with economic and social challenges affecting health service allocation.

2 Literature review

2.1 Utilization and distribution of health resources

The overall health system is unstructured, complex, and pluralistic, lacks effective coordination and governance, and has many actors with different vested interests (22). Due to these characteristics, there are many regions in the world facing the problem of shortage or waste of health resources, which essentially reflects the imbalance of health resources distribution (23). Global health resources are usually provided by different institutions, such as public hospitals, private hospitals, profit, and non-profit organizations. Public hospitals are the main providers of health resources in most countries, and their supply is more reflected in relatively unprofitable services, which are the most needed public health resources for ordinary people (24). Therefore, the resources of public health services can reflect the basic health level of a place. The imbalance in the distribution of public health resources is mainly caused by the political tradition and concept of the country, which leads to various inequalities through the transmission mechanism of the labor market and the national redistribution system (including the proportion of government expenditure on public health and services) (25). This inequality further affects the health status of individuals, such as differences in infant mortality and life expectancy (26). Now, with the improvement of economic development, people's demand for health services is increasing, and the public health resources in many developing countries are facing great challenges in this situation (27, 28). In the face of serious challenges, many developing countries are more prone to the distribution of health resources, and this lack of access to health services has exacerbated the poverty situation of the lower class, leading to the widening trend of health inequality (29). Many of the most effective pro-poor health interventions remain underutilized, while less cost-effective interventions are funded. In these developing countries, the allocation of health resources is even more unequal (30).

The unequal distribution of health resources is also one of the negative externalities of some institutional reforms, such as fiscal decentralization, which reduces the government's ability to redistribute income, and with reduced transfer payments and tighter local budget constraints, governments in poor areas must cut spending on social development (31). Secondly, increasing market competition has also severely affected state-owned enterprises, as it is difficult for them to fulfill the dual tasks of maximizing profits and providing welfare at the same time. As a result, state-owned enterprises in many countries have embarked on a process of privatization or mixed ownership reform (32). Others have had to lay off workers and cut benefits (33). So, their original role as providers of social welfare has thus been weakened. At the same time, due to the scale effect and agglomeration effect, both state-owned and private enterprises are concentrated in big cities, the government income in big cities is increased, and the allocation of medical resources is particularly generous (34). For some developing countries (such as China, India, etc.), the density of hospitals and the number of high-end service equipment in some big cities have reached

the level of Western developed countries, but small cities or other areas have returned to the state of shortage of doctors and drugs, but deepened the inequality of public health resources (35, 36).

There are many existing factors leading to the unequal allocation of health resources. Specifically, the overall investment is limited, this means that when resources are allocated, regions are faced with limited funds for the construction of medical facilities, training of medical personnel, and implementation of public health programs. This lack of overall expenditure directly affects the soundness and popularization of the health service system, making the allocation of public health resources more difficult in some remote areas, especially in poor areas (37). On the other hand, high levels of public health investment do not necessarily guarantee full equity, if the cost of health care is high, then some socially and economically disadvantaged groups cannot afford the high cost of health care. This has led to certain socioeconomic disparities in the utilization of health services, making it possible for some people to lack access to timely and quality medical care (38). In addition, the non-profit nature of public hospitals and the market-oriented survival mode have been seriously divided, some medical institutions have fallen into a state of disorderly competition, and some pharmaceutical industry executives rely on information asymmetry, industry technology monopoly, and inflated drug prices to make profits, further aggravating the trend of abnormally high medical costs and waste of medical resources (39).

Besides, the limited overall public health resource allocation and the policy of maximizing efficiency have led to the emergence of a tiered hospital system. In many countries, hospitals are graded based on the severity, urgency, and complexity of diseases. Different levels of medical institutions are responsible for the treatment of different diseases. People typically seek medical care at local lower-level hospitals, and only escalate to higher-level hospitals if they find their health issues cannot be resolved at the lower level (40). This grading system is conducive to overall efficiency, with a large number of general diseases being treated by doctors in general hospitals, and more competent hospitals and doctors dealing with more difficult diseases. However, the problem is that many Grade A hospitals produced by this system are concentrated in some developed or more populated cities, whereas less developed cities. Although this ensures efficiency in the case of limited input, it affects equity (41). This not only makes residents in some areas face greater pressure on health services, but also aggravates the gap in medical resource allocation between developed and underdeveloped cities, urban and rural areas. Patients in less developed areas who are unsure of their condition and want a definitive diagnosis or treatment must be referred to a higher-level hospital and have to spend a lot of time and energy traveling to developed areas (42). The regional unequal allocation may also lead to patients facing higher transportation and time costs when seeking health services, which in turn deepens the medical dilemma of socially and economically disadvantaged groups (43).

2.2 Urban development and allocation of health resources

In the period of rapid development of each country, people tend to focus on the developed cities with large populations, ignoring other regions. However, the *per capita* disease burden and the need for health care are actually higher in places far from major population centers (44). The lack of attention to other urban and rural areas has resulted in unequal allocation of public health resources (e.g., number of doctors, number of beds, etc.) (45). However, the moderate and equitable distribution of basic health resources throughout the population is an important basis for a country's social safety net and a necessary condition for maintaining a country's social stability. On the whole, when the distribution of social and economic resources inevitably tends to be polarized, the equitable distribution of basic medical and health resources becomes more important for maintaining social stability. In addition, from the individual point of view, the adequacy, publicity, and convenience of healthcare services also have a significant impact on residents' happiness in life (46).

In recent years, various countries have introduced many policies to deal with this problem, and the fairness of public health resource allocation has been improved in some countries, but it is still serious (47). In response to this challenge, it can be alleviated through cooperation mechanisms between different cities, including sharing health resources, so as to promote better coverage of health services in different cities, thereby improving the overall level of public health services (48). At the same time, some medical networks can improve the efficiency of referral by quickly sharing the information of referred patients, so as to reduce the damage to equity caused by referral problems caused by hospital classification (49). On the other hand, starting from the population level, paying attention to the small cities that are often ignored is also an effective way to promote the fair allocation of medical resources (50). By providing more health resource support to these cities, more accessible health services can be achieved, making the overall distribution of health resources more equitable.

Cities in developing countries have mostly adopted policies of rapid expansion over the past few decades, which has led to urban land sprawl and real estate booms. However, many small cities have not achieved the expected population and economic growth, but have experienced population decline and urban contraction (51). City shrinkage is fundamentally defined by population loss. Other factors include insufficient endogenous dynamism due to industrial decline and a serious homogenization of population structure. All of these can be considered as the disappearance of urban characteristics (52). The shrinking of these less developed cities is not the result of economic decline in the general sense, but due to the imbalance of regional development in the country in the past decades (53), which may lead to the spatial mismatch of "population and public resources" (54). It is unreasonable for local governments in shrinking cities to reduce the allocation of public health services in shrinking cities, which will further aggravate the problem of health equity. On the contrary, the improvement of medical quality can also reverse and promote the economic growth of cities, so more attention should be paid to the quality of health resources provision (55). In this way, the polarization of urban public health resources between different cities can be reduced (56).

Furthermore, the equity allocation of health service resources is closely related to factors such as government decision-making and talent cultivation. For example, some city leaders do not understand the allocation of medical resources, which leads to bad phenomena. City leaders have an insufficient understanding of the allocation and distribution of medical resources and often rely on experience in practice, which may lead to inaccurate and incomplete decision-making (57). This can take the form of oversupply in some regions and

scarcity in others, increasing inequality in health care. In addition, there is a mismatch between the academic content of students within inner-city universities and the practical applications offered by public health professionals in the workplace. This may stem from a disconnect between academic programs and actual health service needs, a mismatch that can manifest in a lack of practical skills, a misperception of health service needs, and a lack of in-depth understanding of public health challenges that make it difficult for students to adapt to the actual work environment after graduation (58). Other factors that affect the equity of health services are the different utilization rates of health resources in cities in different regions. Different types of cities, such as tourist cities and industrial cities, have significant differences in demand and utilization of medical resources due to their special economic, social, and demographic structures, which may affect the service results for residents (59).

3 Data and method

3.1 Data resource

The data set utilized for this study was obtained from the *China City Statistical Yearbook*, covering 2010 to 2020. We extracted the number of hospital beds and doctors as dependent variables representing health services. The number of hospital beds refers to available beds in each city in different years.

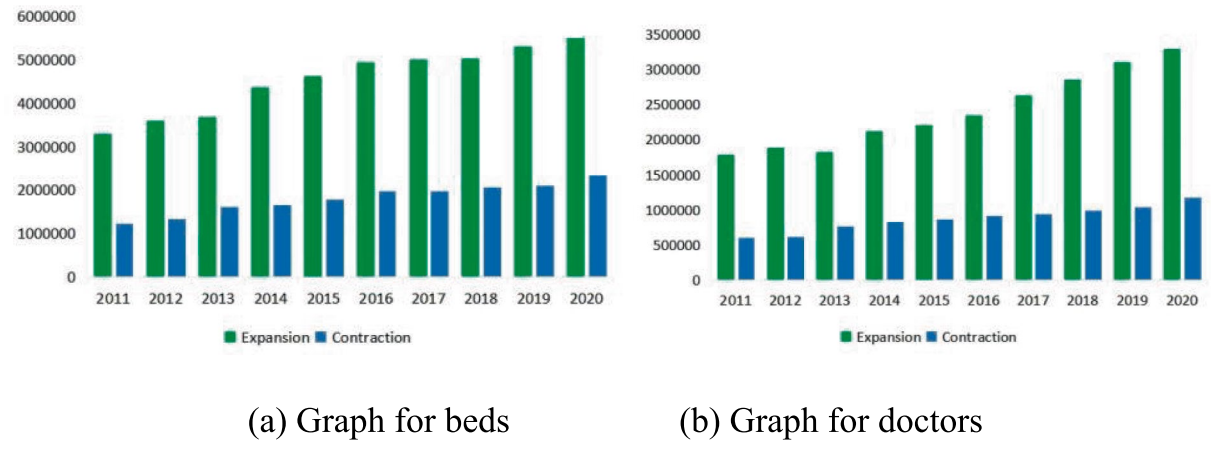
The independent variable in this study was the population change rate, calculated using 2010 as the base year. Data from 2020 were chosen because the data source was China's Sixth National Population Census. If a city's annual population growth rate is negative, it indicates city contraction compared to 2010. This paper used a binary variable to record this, with dummy variables 1 and 0 representing city contraction and expansion, respectively. This paper employed a breakpoint regression approach, using a 0-population change rate (indicating the city is neither contracting nor expanding) as the breakpoint to analyze the situation when the number of city-provided health services is contracting or expanding. Figure 1 presents a dual bar chart illustrating health services delivery in expanding and contracting cities from 2011 to 2020. The figure comprises two sub-figures: (a) represents the number of beds, and (b) represents the number of doctors.

This study used several control variables to account for potential influences, including *per capita* GDP, financial autonomy, and the delivery of other public services, such as the number of primary schools and full-time (FT) teachers in primary schools. Previous research has shown that economic development and financial autonomy will affect the delivery of public services by local governments (60). In addition, government concerns heavily subsidize health services and education (8). Table 1 provides descriptive statistics summarizing the sample's essential characteristics. However, there was missing data for the *per capita* gross domestic product (*per capita* GDP) in 2017, and the data for other years were complete. A linear interpolation method was employed to estimate the missing *per capita* GDP value for 2017.

3.2 Empirical model

The study employed a regression discontinuity (RD) approach to analyze the causal relationship between city shrinkage and health services delivery. The regression discontinuity method applies to this study and can effectively identify and handle causal relationships. RD allocates interventions by utilizing a clear threshold (in this study, the point where urban population change equals 0), thereby reducing selection bias and improving internal effectiveness. This approach treated the number of health services provided as the dependent variable and the population change rate as the independent variable. Some control variables were incorporated to account for potential confounding factors and construct a robust regression discontinuity model:

$$H_{it} = \alpha + \beta\left(x_{it} - c\right) + \delta D_{it} + \gamma\left(x_{it} - c\right) D_{it} + \pi control_{it} + \lambda_i + \tau_t + \varepsilon_{it} \quad (1)$$



(a) Graph for beds (b) Graph for doctors

FIGURE 1
Delivery of health services in expansion and contraction cities.

TABLE 1 Descriptive statistics.

Variable	Mean	SD	Min	Max
Number of hospital beds	20352.26	18033.23	1,352	177,410
Number of doctors	10515.92	10371.85	777	118,541
Population (million)	4.46	3.41	0.23	31.98
GDP *per capita*	47392.49	33760.66	1227.6	256,877
Financial autonomy	0.45	0.22	0.06	1.54
Primary schools	612.98	548.74	18	5,248
FT teachers in primary schools	18118.12	13105.14	786	130,610

Sample size 2,739.

TABLE 2 Regression discontinuity analysis of health service provision.

	Model 1		Model 2	
Variables	Number of hospital beds		Number of doctors	
Population change rate	−1409.322**	(558.1896)	−642.0145***	(250.0724)
Control variables	Yes		Yes	
Fix effects	Yes		Yes	
Observations	2,736		2,739	

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

In Eq. 1, i denotes a province, and t denotes a year; H_{it} denotes the number of health services provided, including the number of hospital beds and the number of doctors; The coefficient β denotes the estimated effect of the population change rate; x_{it} denotes population change rate; $x_{it}-c$ denotes a normalisation of x_{it}, meaning the breakpoint of $x_{it}-c$ is 0. δD_{it} denotes processing state; $(x_{it}-c)D_{it}$ denotes introduced as the interaction term, meaning the slopes on each side of the breakpoint can differ. $control_{it}$ denotes control variables, λ_i denotes the city fixed effect, τ_t denotes the year, and ε_{it} denotes the independent random error term. Then, we utilized the fixed effects model to comprehensively analyze the various factors that influence health services delivery:

$$H_{it}=\alpha+\sum\beta_{itk}x_{itk}+\lambda_i+\tau_t+\varepsilon_{it} \quad (2)$$

In Eq. 2, H_{it} also denotes the number of health services delivered; k donates different independent variables x, including GDP *per capita*, financial autonomy, value added by tertiary industry, primary schools, FT teachers in primary schools; λ_i and τ_t denote the province and the year fixed effect; ε_{it} denotes the independent random error term.

In this study, we use the Stata 17.0 to analyze the data. Stata is a data analysis and statistical software widely used in economics, sociology, and other fields. To determine the suitability of the regression discontinuity model, as shown in Appendices A,B, we tested the sample distribution and fitting of the model. Meanwhile, we also conducted a sensitivity analysis on the model, as shown in Appendix C. From the results, the model meets the requirements of regression discontinuity.

4 Results

4.1 Health services in city shrinkage

Table 2 reveals the impact of the population growth rate on health services, specifically the number of beds and doctors. Both regression models exhibited statistically significant breakpoints, suggesting city shrinkage potentially exerted a causal effect on health services provision. We found from the results that city shrinkage has a causal relationship with both the number of hospital beds (−1,200.4131, $p<0.05$) and doctors (−540.0454, $p<0.05$). A negative coefficient might indicate that contracting cities have larger disadvantaged populations and need more health resources; alternatively, it might indicate that local governments have wasted resources by forcing the delivery of too many public services to reduce the rate of city contraction. Some expanding cities may face run-on health resources, as the economy and population of an expanding city will increase before available health services do. Another possibility is that a relatively low delivery of health services limits an expanding city's continued expansion, resulting in a lower-than-expected population growth rate.

Figure 2 showcases RD graphs corresponding to the two models. To the left of the red line, the graph illustrates the number of health services provided by local governments during city contraction, with the corresponding fitting line in blue. To the right, the graph portrays the number of health services provided by local governments during city expansion, with the corresponding fitting line in green. The blue and green lines are visibly divergent on both sides of the red line.

Notably, the blue line exhibits a relatively flatter slope, while the green appears steeper. This indicates that when cities contract, local government's delivery of health services remains relatively stable, despite a substantial population decline. Initially, expanding cities might be unable to keep up with the expansion rate. However, as expansion increases, local government services in many cities change significantly. These observations suggest that the impact of population change on health services delivery differs depending on the city's population trend (expansion or contraction). During city shrinkage, local governments may be less willing to invest in health service resources.

4.2 Influential factors in health service provision

Table 3 displays the effects of various variables on providing two types of health services. All variables demonstrate statistical significance. A positive *per capita* GDP coefficient (beds: 0.0782, $p<0.001$; doctors: 0.0649, $p<0.001$) indicates that cities with better economic development are more capable of investing in health services. Similarly, a positive financial autonomy coefficient suggests that cities with a higher government revenue-to-expenditure ratio (and, consequently, more disposable income) have a greater capacity to allocate resources to health services. Although local government financial autonomy is beneficial for the

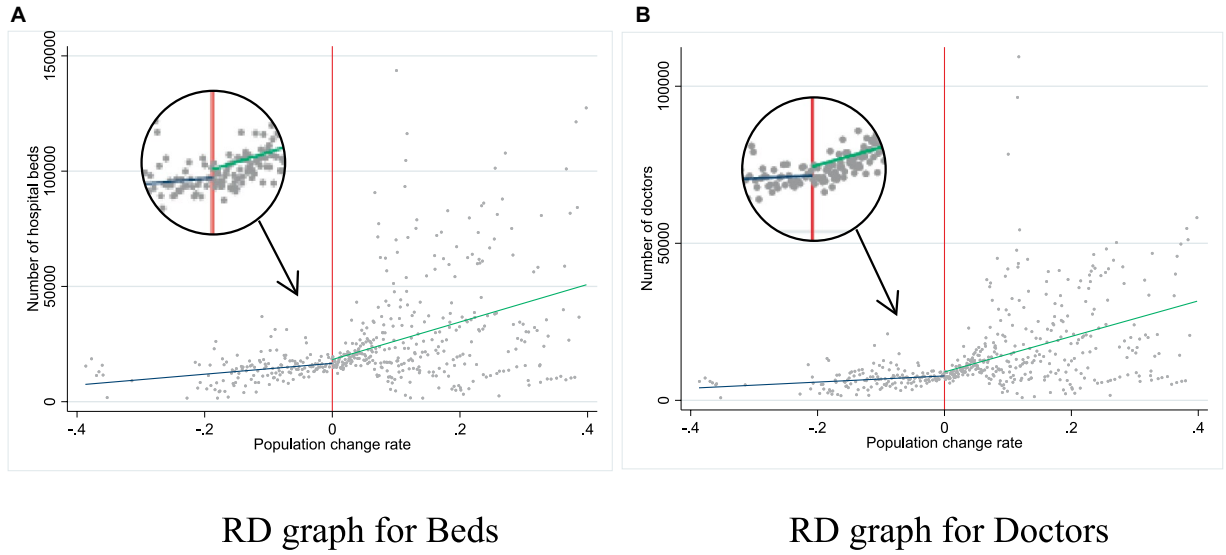


FIGURE 2
The effect of city shrinkage on the number of health services provided by local government.

TABLE 3 Regression analysis with fixed effects model on control variables.

	Model 3		Model 4	
Variables	Number of hospital beds		Number of doctors	
GDP *per capita*	0.0782***	(0.0086)	0.0649***	(0.0050)
Financial autonomy	2,881.7673**	(1,260.6347)	902.3542	(739.3160)
Primary Schools	−8.8162***	(0.5636)	−5.3949***	(0.3305)
FT teachers in primary schools	1.3008***	(0.0235)	0.7061***	(0.0138)
Fixed effects	Yes		Yes	
Constant	−17,591.8060***	(883.8212)	−14,484.8023***	(518.1289)
Observations	2,731		2,734	
R-squared	0.766		0.757	

Standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

rational allocation of material resources (2,881.7673, $p < 0.05$), its impact on human resource allocation is limited. In addition, the coefficient for the number of primary schools was negative; this can be attributed to the significant financial expenditure required to construct public primary schools. When governments invest heavily in school construction, resources for health services might be impacted. This also illustrates that government investment in other public services also affects the allocation of health service resources.

4.3 Robustness test

We performed a regression analysis to assess the robustness of our model, after excluding data from cities in China with higher political status or relatively advanced economic development (i.e., Beijing, Shanghai, Chongqing, Tianjin, Guangzhou, and Shenzhen) to ensure that those cities' specific characteristics did not solely drive our findings. By excluding them, we obtained a more diverse sample of cities, allowing us to examine the relationship between population change and health services delivery in a broader context.

In Table 4, the results of the robustness checks using the RD models reaffirm the coefficients' significance (beds: −1,200.4131, $p < 0.05$; doctors: −540.0454, $p < 0.05$), even after excluding the six more-developed cities, strengthening our findings, and suggesting that the relationship between population change and health services delivery is consistent and robust across a broader range of cities.

5 Discussion

5.1 Statement of principal findings

This is the first study to identify that city shrinkage affects health services delivery provision. Three critical discussions can be drawn from its findings.

Firstly, we find a causal relationship between city shrinkage and the allocation of health service resources. When a city experiences contraction, health service resources can significantly decrease. Specifically, there is a causal relationship between city shrinkage and the number of hospital beds and doctors. As Figure 3 shows, health service provision increases significantly in expanding cities, while contracting cities maintain a smooth curve, likely determined by policymakers' inherent preferences in the face of population loss. From 2010 to 2020, China was in a rapid population aging phase. Older adult populations need more health services, meaning the number of primary healthcare users did not reduce as quickly as some cities' populations. Additionally, governments must maintain the status quo for stability reasons; if too many health services are eliminated, more people will leave the city, shrinking it further and creating a vicious circle.

TABLE 4 Robustness analysis of regression discontinuity for health service provision.

	Model 5		Model 6	
Variables	Number of hospital beds		Number of doctors	
Population change rate	−1,200.4131**	(499.8058)	−540.0454**	(243.1996)
Control variables	Yes		Yes	
Fixed effects	Yes		Yes	
Observations	2,684		2,687	

Standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Second, it is important to consider endogenous factors for the growth of city health services, such as how attractive the city is to talented individuals. Most previous studies fail to comprehensively investigate health services (the number of hospitals, hospital beds, and doctors) from a socio-economic perspective, instead considering only minimal socio-economic factors. It takes work to attract talents, especially graduates and young doctors, to join hospitals in contracting cities, as many healthcare professionals might prefer to work in larger cities with more job opportunities and better pay. Although health reform is gradually deepening, hospital staff mobility is still very high. Hospitals pursue individuals with high academic qualifications and need a scientific, practical talent

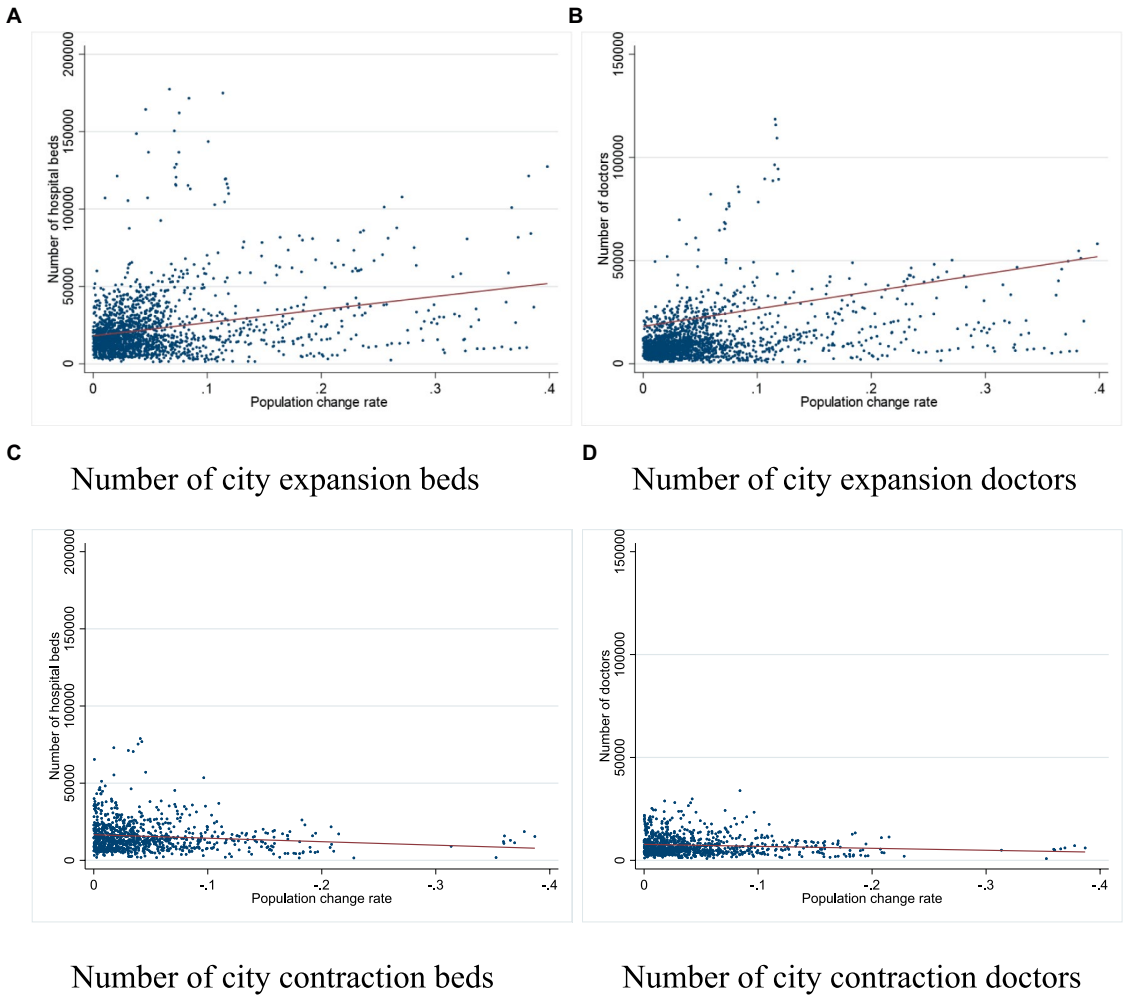


FIGURE 3
Population change rates affect health services provision.

selection mechanism. It is impossible to fully and effectively consider whether talents' values and personal pursuits align with the hospital, resulting in a period in which hospital talents seem vibrant. Still, it has laid the groundwork for talent loss in the long run. However, most expanding cities need more health services, so more doctors stay in hospitals and are given few opportunities, leading to a sense of not belonging to the organization and creating a vicious cycle.

Third, there is the issue of patient equity—i.e., whether health services are fairly distributed to all patients regardless of the type of city or demographic change in the context of urban contraction and expansion. On the one hand, we are very concerned about patient equity in shrinking cities. As the population of a shrinking city decreases, patients face reduced delivery of health resources. On the other hand, we also find that expanding cities may face issues such as resource constraints and extended queue times, which can affect health equity. Some studies illustrate that Chinese patients have problems with overcrowding and long waiting times for medical treatment (61). The decrease in population has led to a decrease in the willingness of the government to invest in public services, which has also affected medical services. The city shrinkage essentially damages the benefits of residents' health services, laying hidden dangers for health services equity. Therefore, intersectional equity is therefore key to realizing the equity of health service provision under city shrinkage. This intersectional equity is reflected in human resources, financial resources, etc. (62). The government needs to pay attention to the impact of population changes.

5.2 Strengths and limitations

The study's results show that the government prefers reducing health services delivery in contracting cities and increasing health services delivery in expanding cities. In our fixed-effects model, decreases in health services correlated with reductions in other public services, meaning city policymakers base public services investment decisions on population. When the population decreases, they scale back their investment in health and other public services or maintain the current level. This may be because population decline decreases demand for health services, reducing the incentive to invest in health services. At the same time, a declining population also leads to decreased fiscal revenues, so governments prioritize the efficient use of budgetary resources to meet the remaining population's needs for essential healthcare services.

We note three limitations. First, we need to further explore the mechanisms and pathways of city contraction and expansion in health services delivery. This study identifies macro correlations through quantitative analysis but does not delve into their specific underlying mechanisms. For example, the reasons why health services remain stable during city contraction might involve government policies, community organization, and resource allocation. Second, some data were missing due to changes in the statistical methods used by *the China City Statistical Yearbook*, so interpolation was used, meaning the results might deviate slightly from reality. Third, this study lacks an examination of individual health service needs. Against the backdrop of city shrinkage, further research is needed to explore the situation of individuals accessing services. Research needs to obtain citizens' perceptions of health services to understand whether it affects the health service equity of individuals. This is also the focus of future research.

5.3 Interpretation within the context of the broader literature

Existing studies on city shrinkage have mainly focused on developed countries; more research is needed on how city areas in developing countries cope with population changes and provide health resources. Considering the economic, cultural, and social environmental differences across countries and regions, in-depth research on city areas in developing countries is needed to fully understand the allocation methods and influencing factors of health service in city shrinkage contexts. Some developing countries prioritize the accessibility of primary medical services, often emphasizing fundamental needs while overlooking quality issues (63), perhaps due to challenges that pressure these countries' fragile healthcare systems—including rapid urbanization, environmental degradation, and unfair global trade conditions (64).

As a unique, developing country, China experiences rapid expansion and ongoing shrinkage in different cities. Therefore, research within the Chinese context is fundamental. As a resource-limited developing country with a large population, China faces challenges such as increasing population, aging, and (more recently) epidemics. Health resource delivery is receiving increased government attention, and investments in various healthcare projects are rising. However, it is essential to acknowledge that health resources are inherently limited. China has undergone several reforms in health services to address the challenges related to healthcare resources, ultimately agreeing with the government's dominant role in health services. The government must be more critical in health services (65), especially given that recent scholarship proves that medical marketization is unreasonable for most developing countries (64–66).

5.4 Implications for policy, practice, and research

Our study offers some implications for health services and policy designs for equity in health services provision. Governments and policymakers need to take appropriate measures to ensure patient equity: A sound planning and policy mechanism should be established to allocate healthcare resources and balance supply and demand reasonably. This includes developing comprehensive healthcare planning, anticipating the impact of demographic changes on healthcare demand in advance, and adjusting the resource allocation accordingly.

We should focus on the delivery of medical services in shrinking cities. The decrease in population may reduce the government's willingness to invest in health resources. This may be a key factor contributing to the unfairness of medical services. Therefore, it is necessary to ensure that government investment in medical services is not affected by demographic factors.

Monitoring and evaluation mechanisms for healthcare services need to be strengthened to identify and correct inequities promptly and protect patients' equal rights and interests in the event of urban contraction and expansion.

6 Conclusion

Our findings highlight the challenges that city shrinkage poses to health service provision in China. The consequences of city shrinkage for health service provision are complex and multifaceted, impacting access to healthcare opportunities for residents. Specifically, on the one hand, a causal relationship exists between city shrinkage (expansion) and the delivery of health service resources. On the one hand, there is a significant gap in the delivery of health service resources between shrinking and expanding cities. The changes in the urban population have led to an imbalance in resource allocation. On the other hand, patients confront challenges due to limited access to health services. Most studies have confirmed that the expansion of cities intensifies competition for health service resources. But in shrinking cities, the government lacks the willingness to supply resources, resulting in stagnant development of health services. In conclusion, addressing the issues of shrinkage and resource inequities demands targeted policies and programs that prioritize the spatial distribution of health resources to promote regional development and improve health outcomes.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

HW: Writing – review & editing. KX: Writing – original draft, Writing – review & editing. HF: Writing – original draft. HL: Writing – original draft. HZ: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1330921/full#supplementary-material

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The cross-regional settlement methods in hospitals and the treatment-seeking behavior of patients with malignant tumors in China: an evolutionary game model

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Background: Cross-regional settlement management is a key indicator of national health insurance system maturity. Given the significant demand for cross-regional medical treatment among Chinese patients with malignant tumors and the territorially managed health insurance system, further research is necessary to explore the relationship between hospital settlement methods and treatment-seeking behaviors among these patients. This study introduces and validates an evolutionary game model that provides a theoretical foundation for direct settlement policies in cross-regional treatment.

Methods: An evolutionary game model was constructed with patients and hospitals serving as strategic players within a dynamic system. This model integrates the patients' treatment utility, medical and nonmedical costs, and hospitals' financial and technological advancement benefits.

Results: The evolutionary stability analysis revealed seven-game outcomes between hospitals and patients with malignant tumors. The numerical simulations suggest an evolutionary convergence toward strategy (1, 0), indicating a trend where patients with malignant tumors opt for cross-regional treatment, yet hospitals choose not to implement a direct settlement policy. Parameter sensitivity analysis showed that the parameters set in this study affected player behavioral choices and game equilibria.

Conclusion: A strong demand for cross-regional medical treatment among Chinese patients with malignant tumors, and some hospitals require more incentives to implement cross-regional settlements. The key factors influencing the willingness of some patients with malignant tumors to resettle include the costs of in-area medical care, costs of cross-regional treatment without direct settlement, and the utility of cross-regional treatment. Technological advancement benefits and input costs influence some hospitals' motivation to adopt cross-regional settlements. Policy adjustments that effectively implement direct settlement policies can facilitate equilibrium, enhance the initiatives of some local health insurance management departments, improve the accessibility and efficiency of medical services, and reduce nonmedical expenses for patients.

KEYWORDS

cross-regional treatment, direct settlement, malignant tumors, treatment-seeking behavior, evolutionary game

1 Introduction

Cross-regional treatment refers to the act of an insured individual seeking medical care in areas outside their insurance coverage under the healthcare security system (1–3). The uneven geographical distribution of healthcare resources is a major factor driving the increase in the number of patients opting for medical services in various locations (4). The scope of insurance coverage varies between insured and uninsured areas, with the insured areas encompassing entities such as countries, cities, and other administrative regions (5). For instance, within the European Union (EU), each member state typically has its own insurance coverage zone. To improve citizens' access to healthcare, the EU offers the European Health Insurance Card, which allows nationals from member states to receive medical services across the union. The variability in healthcare policies among countries necessitates full harmonization of medical insurance payments and reimbursement standards. The EU responded by implementing Directive 2011/24/EU of the European Parliament and Council on the application of patients' rights in cross-border healthcare, ensuring patients' rights to receive medical services and insurance reimbursements in other EU countries (6).

Due to China's household registration system, cross-regional treatment is divided into unplanned and planned categories. The unplanned category typically includes short-term business travelers, migrant workers, and retired residents relocating to different regions, whereas the planned category is driven by individuals seeking superior healthcare services due to the unequal distribution of medical resources (7, 8). This study is focused on planned cross-regional settlements. Unlike the EU, China's medical insurance pooling is limited to the city level, leading to cross-regional settlement reimbursements for patients (9). With this flexible health insurance management mechanism, China has achieved a medical insurance coverage rate of over 95% for its 1.4 billion population, approaching the threshold of universal health coverage (10). Although significant progress has been made in health insurance coverage, it has also introduced a unique challenge: the issue of cross-regional settlement (11). Residents seeking medical care outside their insured areas encounter obstacles related to inconsistent financing and payment standards, which are often exacerbated by complex reimbursement processes. In response, China has implemented policies for cross-regional settlements. In 2020, the Chinese government issued "Opinions on Deepening the Reform of the Medical Security System," proposing further improvements in the direct settlement system for cross-regional medical treatment (12). In July 2022, the Chinese government issued the "Notice on Further Improving the Direct Settlement of Basic Medical Insurance for Cross-Province Medical Treatment," aiming to increase the direct settlement rate of inpatient expenses by over 70% by 2025 (13). The direct settlement policy for cross-regional medical treatment meets the needs of non-insured residents to some extent. In the first three quarters of 2023, China had 84.54 million cross-province direct settlement cases for medical treatment, reducing individual out-of-pocket expenses by 15.5 billion dollars (14).

Patients with malignant tumors in China require direct settlement for cross-regional medical treatment. Regardless of economic status across countries, malignant tumors are one of the most common causes (15). In China, malignant tumors rank second in the mortality rate of resident diseases (16), with an annual increase of 21.6% in deaths from these tumors (2005–2020) (17). Due to the concentration of high-quality resources for cancer diagnosis and treatment, among patients undergoing cross-regional treatment, those with malignant tumors constitute one of the largest groups (2, 5, 11). A Research shows that from 2015 to 2020, chemotherapy for tumors and lung cancer ranked first and fifth, respectively, among cross-regional treatments in China. Even in 2020, a year after the COVID-19 pandemic, the proportion of patients traveling for chemotherapy continued to rise (18). However, an imperfect real-time settlement system for cross-regional medical treatment often requires patients to make advance payments, adding a considerable financial burden on families (19). Lengthy reimbursement cycles and complex travel arrangements exacerbate this problem, adversely affecting the daily lives of patients and their families (20). Moreover, the frequent visits and follow-ups required for treating malignant tumors further intensify the economic strain on families (21).

In cross-regional direct settlement issues in China, hospitals and patients with malignant tumors have different considerations. The primary objective of hospitals is to enhance their technical capabilities and service quality to achieve sustainable development (22). By implementing direct cross-regional settlement, hospitals can attract more patients, thus continuously optimizing and improving their expertise. When treating cross-regional patients, hospitals often adopt a fee-for-service approach that allows them to generate more financial revenue (23). In 2023, the number of hospitals in China implementing direct settlement for inpatient expenses increased by 19,600 from the previous year, indicating that despite the widespread implementation of the policy, not all institutions have adopted this service (24). One significant challenge is the information technology transformation of medical insurance platforms, which incurs substantial maintenance costs (25). Additionally, hospitals face risks associated with higher upfront financial payments and longer reimbursement cycles (26). For patients with malignant tumors, focusing on securing improved diagnoses and treatment outcomes through direct cross-regional settlement while reducing the healthcare burden resulting from inconvenient medical insurance in their local areas is essential (23). Since oncological treatment resources are primarily concentrated in first-tier cities and provincial capitals, patients with malignant tumors often opt to seek medical care in these areas to access more specialized expertise and enhanced treatment outcomes (17). Importantly, the settlement method for cross-regional medical treatment matches the medical insurance coverage of the treatment location, following the specific drug formulary, diagnostic procedure list, and medical consumables catalog (27). The costs of services not listed in these catalogs are the patient's responsibility and are not covered by insurance. These locations typically offer more comprehensive insurance catalogs, allowing patients to receive higher reimbursements and reduce their out-of-pocket expenses (28). Patients can also significantly reduce the time and effort required to process medical insurance reimbursements (11).

Evolutionary Game Theory was first introduced by John Maynard Smith and George R. Price in their seminal paper "The Logic of Animal Conflict," published in the journal Nature, applying

TABLE 1 Strategic combinations of patients with malignant tumors and hospitals.

Strategies		Hospitals	
		Direct settlement for cross-regional medical treatment	Indirect settlement for cross-regional medical treatment
Patients with malignant tumors	Cross-regional treatment	Patients seek cross-regional treatment, hospitals' direct settlement	Patients seek cross-regional treatment, hospitals' indirect settlement
	In-area medical care	Patients seek in-area medical care, hospitals' direct settlement	Patients seek in-area medical care, hospitals' indirect settlement

Darwinian principles to the study of strategic interactions within populations (29, 30). It applies mathematical principles to predict and understand behavior in a variety of complex systems ranging from animal dynamics to human social and economic interactions (31). It is increasingly applied across various fields, such as mathematics, economics, and business management (32). Its extension to the field of healthcare management is also noteworthy, encompassing areas such as healthcare reforms (33), healthcare and social care coordination (34), and early warning of public health emergencies (35).

In this study, Evolutionary Game Theory has several advantages. Initially, it broadened the scope of analysis from individuals to groups, increasing its relevance and applicability (35). Second, it employs population thinking, emphasizing heterogeneity within groups and allowing for individual strategies within the same group (36). Third, it emphasizes the importance of the historical context and frequency of strategies (31, 37), which helps understand the evolution of behaviors within patient and hospital groups over time. Furthermore, despite data challenges such as regional dispersion and privacy in China (18), it can explore the interactive behaviors between hospitals and patients and conduct sensitivity analyses to test outcomes under various parameters, even without complete data. Finally, it assumes limited rationality, reflecting more realistic decision-making processes based on partial information and limited decision capabilities and aligning closely with the practicalities of real-world scenarios (38).

In the field of public health, research on cross-regional medical treatments for patients with malignant tumors has primarily focused on mobility (15, 39), service utilization (3, 40), and influencing factors (2, 5, 11). These studies overlooked the strategic interactions between patients and healthcare providers, as well as the significant impact of direct settlement policies. Therefore, this study uses Evolutionary Game Theory to provide new insights into the relationship between the behaviors of patients with malignant tumors and hospital policies on cross-regional settlement, aiming to fill the gaps left by previous research. Compared with international practices, China lacks policy support for the settlement of cross-regional medical treatments for patients (41). This study aimed to uncover the group evolutionary paths of patients with malignant tumors and hospitals in the absence of policy influence, providing a theoretical foundation for policy development.

In the subsequent sections of this study, Section 2 presents the parameters and assumptions of the evolutionary game model. Section 3 presents the construction of the model and analysis of the equilibrium of the system. Section 4 presents the numerical simulations. Section 5 discusses the findings, provides the theoretical and policy implications, and highlights the limitations of the study. Finally, Section 6 presents the conclusions drawn from the study.

2 Model design

2.1 Description of players

In the implementation of the direct settlement policy for cross-regional medical treatment, the primary stakeholders are hospitals and patients with malignant tumors. Both groups, considered as limited rational players, continually adapted their strategies based on ongoing interactions, ultimately aiming for a stable system equilibrium. The strategic combinations of patients with malignant tumors and hospitals are listed in Table 1.

In this study, "hospitals" refer to hospitals that have the autonomy to decide whether to implement the direct settlement policy. Considering the municipal-level management characteristics of China's medical insurance policy, a direct settlement policy has regional features (42). For example, in Anhui Province, hospitals can independently choose whether to adopt a direct settlement policy by submitting an application to the Provincial Cross-regional Medical Treatment Management Center (43). However, not all scenarios are considered, and a considerable range of real-world settings are represented. It assumes that hospitals decide between "direct settlement for cross-regional medical treatment" and "indirect settlement."

This study focused on patients with malignant tumors undergoing planned cross-regional medical treatment. This includes individuals diagnosed with cancer types that present greater clinical challenges and poorer prognoses, such as pancreatic cancer. In contrast, patients with malignant tumors that present less clinical difficulty and have better prognoses, such as thyroid cancer, were not included in this study. It assumes patients with malignant tumors decide between "cross-regional treatment" or "in-area medical care."

2.2 Model assumptions and parameters setting

In the assumptions of this model, the policy for direct settlement of cross-regional medical treatment includes three characteristics that align with actual conditions. Firstly, regarding policy coverage, it is presumed that all provinces nationwide have

TABLE 2 Model assumptions for patients with malignant tumors.

Case	Parameters	Definition	Ranges
Cross-regional treatment	x	Probability of choosing cross-regional treatment	$0 \le x \le 1$
	U_1	Utility of cross-regional treatment	$U_1 > U_2$
	S_1	Medical costs paid by patients after cross-regional treatment	$S_1 < S_2$
	C_1	Other costs of cross-regional treatment with direct settlement	$C_1 < C_2$
	C_2	Other costs of cross-regional treatment without direct settlement	$C_1 < C_2$
In-area medical care	$1 - x$	Probability of choosing in-area medical care	$0 \le y \le 1$
	U_2	Utility of in-area medical care	$U_1 > U_2$
	S_2	Medical costs paid by patients after in-area medical care	$S_1 < S_2$

TABLE 3 Model assumptions for hospitals.

Case	Parameters	Definition	Ranges
Direct settlement for cross-regional medical treatment	y	Probability of implementing direct settlement for cross-regional treatment	$0 \le y \le 1$
	π_1	Financial benefits of implementing direct settlement for cross-regional treatment	$\pi_1 > \pi_3$
	π_2	Technological advancement benefits of implementing direct settlement for cross-regional treatment	$\pi_2 > 0$
	C_3	Input costs of implementing direct settlement for cross-regional treatment	$C_3 > 0$
Indirect settlement for cross-regional medical treatment	$1 - y$	Probability of implementing indirect settlement for cross-regional treatment	$0 \le y \le 1$
	π_3	Financial benefits of implementing direct settlement for local treatment	$\pi_1 > \pi_3$

implemented the direct settlement policy, though not all hospitals proactively offer this service, reflecting real-world practices (44). Secondly, concerning reimbursement ratios, the model assumes that the reimbursement rate for malignant tumor patients seeking treatment outside their insured region exceeds that within their insured location under equivalent treatment conditions. As previously mentioned, this study focuses on unplanned cross-regional medical treatments undertaken by patients in pursuit of superior medical resources; It has been validated that these areas typically have more comprehensive medical insurance catalogs, thereby affording higher reimbursement rates under the same treatment conditions (27). Thirdly, regarding the direct settlement reimbursement process, the model assumes uniformity across provinces: patients use the national medical insurance service platform's APP or the WeChat Mini Program of the National Medical Insurance Administration to apply for cross-provincial medical treatments online and facilitate real-time settlements (45).

Besides, the impacts of COVID-19 or similar public health emergencies are not considered. During the pandemic, the localized management of health policies in China temporarily restricted cross-regional medical treatment (46), which returned to pre-pandemic conditions post-COVID-19. Given the intensified focus on healthcare in the post-pandemic era and the enhanced mobility of the population, there is a potential increase in the demand for cross-regional medical services (47). Therefore, the analysis and conclusions of this study are based on conditions free from such external disruptions, further underscoring the practical significance of our study in a non-pandemic context.

The model assumptions for patients with malignant tumors are presented in Table 2. In the assumptions, x represents the probability of choosing cross-regional treatment, whereas $1 - x$ indicates the probability of choosing in-area medical care, where $0 \le x \le 1$. Medical services are utilized through treatment methods and approaches that improve patient health (48). The utility derived from cross-regional medical care is denoted by U_1, whereas U_2 represents the utility obtained from in-area medical care, where $U_1 > U_2$. Furthermore, studies have indicated that under direct settlement policies, patients with malignant tumors who seek cross-regional treatment incur lower out-of-pocket expenses than those receiving in-area medical care when using the same treatment methods (28). Thus, S_1 signifies the medical costs incurred by patients for cross-regional treatment, whereas S_2 represents the cost of in-area medical care, where $S_1 < S_2$. Additionally, C_1 encompasses other costs associated with cross-regional treatment and direct settlement, such as travel, accommodation, and time-related expenses, whereas C_2 signifies equivalent costs without direct settlement, where $C_1 < C_2$.

The model assumptions for hospitals are presented in Table 3. In the assumptions, y represents the probability of a hospital choosing a direct settlement for cross-regional treatment, whereas $1 - y$ represents the probability of not choosing a direct settlement, where $0 \le y \le 1$. π_1 and π_2 represent the financial and technological advancement benefits, respectively, of choosing a direct settlement for cross-regional treatment. Hospitals that choose direct settlement can attract more cross-regional

TABLE 4 Payoff matrix between patients with malignant tumors and hospitals.

Strategies		Hospitals	
		Direct settlement for cross-regional medical treatment	Indirect settlement for cross-regional medical treatment
Patients with malignant tumors	Cross-regional treatment	$U_1 - S_1 - C_1$ $\pi_1 + \pi_2 - C_3$	$U_1 - S_1 - C_2$ π_3
	In-area medical care	$U_2 - S_2$ $-C_3$	$U_2 - S_2$ 0

patients, who often have more severe conditions and higher medical expenses (23). Consequently, π_3 denotes the financial benefit of not implementing a direct settlement, with $\pi_1 > \pi_3$ and $\pi_2 > 0$. C_3 represents the input costs for direct settlement, including fees for updating the direct settlement information system, payments related to capital turnover pressure, and delayed reimbursements, where $C_3 > 0$.

Based on the parameter assumptions in Tables 2, 3, a Game Payoff Matrix was constructed for patients with malignant tumors and hospitals, as shown in Table 4.

3 Model analysis

3.1 Establishment of the payoff model

The Replicator Dynamic Equation is a dynamic differential equation describing the frequency or prevalence of a group strategy (49). The expected and average payoffs for patients with malignant tumors, denoted P, choosing the cross-regional and in-area medical care strategies are E_{P_1}, E_{P_2}, and E_P, respectively.

Based on Table 4, the expected payoff for patients with malignant tumors who choose the cross-regional treatment strategy is denoted as E_{P_1}, as shown in Equation 1.

$$E_{P_1} = y(U_1 - S_1 - C_1) + (1-y)(U_1 - S_1 - C_2) \tag{1}$$

The expected payoff for patients with malignant tumors choosing in-area medical care is denoted as E_{P_2}, as shown in Equation 2.

$$E_{P_2} = y(U_2 - S_2) + (1-y)(U_2 - S_2) \tag{2}$$

The expected payoff for patients with malignant tumors who adopt the mixed strategy is E_P, as shown in Equation 3.

$$E_P = xE_{P_1} + (1-x)E_{P_2} \tag{3}$$

The Replicator Dynamic Equation for patients choosing a cross-regional treatment is $F(x)$, as shown in Equation 4.

$$\begin{aligned} F(x) &= \frac{dx}{dt} = x(E_{P_1} - E_P) = x(1-x)(E_{P_1} - E_{P_2}) \\ &= x*(x-1)*(C_2 + S_1 - S_2 - U_1 + U_2 + C_1*y - C_2*y) \end{aligned} \tag{4}$$

Similarly, the expected and average payoffs for hospitals, denoted, that choose direct and indirect settlement strategies for cross-regional settlements are E_{H_1}, E_{H_2} and E_H respectively.

Based on Table 4, the expected payoff for hospitals that choose direct settlement for cross-regional treatment is denoted as E_{H_1}, as shown in Equation 5.

$$E_{H_1} = x(\pi_1 + \pi_2 - C_3) + (1-x)(-C_3) \tag{5}$$

The expected payoff for hospitals that choose indirect settlement for cross-regional treatment is E_{H_2}, as shown in Equation 6.

$$E_{H_2} = x(\pi_3) + (1-x)(0) \tag{6}$$

The expected payoff for hospitals adopting a mixed strategy is E_H, as shown in Equation 7.

$$E_H = yE_{H_1} + (1-y)E_{H_2} \tag{7}$$

The Replicator Dynamic Equation for hospitals that opt for direct settlement in cross-regional treatments is represented by $F(x)$, as shown in Equation 8.

$$\begin{aligned} F(y) &= \frac{dy}{dt} = y(E_{H_1} - E_B) = y(1-y)(E_{H_1} - E_{H_2}) \\ &= y*(y-1)*(C_3 - \pi_1*x - \pi_2*x + \pi_3*x) \end{aligned} \tag{8}$$

The set of Replicator Dynamic Equations comprising Equations 4 and 8 is given in Equation 9.

$$\begin{cases} F(x) = x*(x-1)*(C_2 + S_1 - S_2 - U_1 + U_2 + C_1*y - C_2*y) \\ F(y) = y*(y-1)*(C_3 - \pi_1*x - \pi_2*x + \pi_3*x) \end{cases} \tag{9}$$

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3.2 Evolutionary system equilibrium analysis

Setting Equation 9 to zero results in five equilibrium points:

$$O(0,0),\ A(1,0),\ B(0,1),\ C(1,1),\ D(x_0,y_0)$$

$$x_0=\frac{C_3}{\pi_1+\pi_2-\pi_3},\ \text{with } 0<x_0<1,$$

$$y_0=\frac{C_2+S_1-S_2-U_1+U_2}{C_2-C_1},\ \text{with } 0<y_0<1.$$

An Evolutionarily Stable Strategy (ESS) is defined as the equilibrium point at which the local dynamics of the replicator dynamic equilibrium point gradually converge to a stable point (50). The evolutionary stability of an ESS can be determined using the determinant and trace of the Jacobian matrix. From Equation 9, the Jacobian matrix J can be obtained as shown in Equation 10. Let the determinant and trace of matrix J be denoted as $\det(J)$ and $tr(J)$, respectively. When an equilibrium point satisfies $\det(J)>0$ and $tr(J)<0$, that is, $\frac{\partial F(x)}{\partial x}<0$ and $\frac{\partial F(y)}{\partial y}<0$, then it is an evolutionarily stable strategy in the replicator dynamics system.

$$J=\begin{bmatrix}\frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y}\\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y}\end{bmatrix} \tag{10}$$

The values of $\frac{\partial F(x)}{\partial x}$, $\frac{\partial F(x)}{\partial y}$, $\frac{\partial F(y)}{\partial x}$ and $\frac{\partial F(y)}{\partial y}$ are shown in Equations 11–14.

$$\frac{\partial F(x)}{\partial x}=(2x-1)*(C_2+S_1-S_2-U_1+U_2+C_1*y-C_2*y) \tag{11}$$

$$\frac{\partial F(x)}{\partial y}=x*(x-1)*(C_1-C_2) \tag{12}$$

$$\frac{\partial F(y)}{\partial x}=y*(y-1)*(\pi_1-\pi_2-\pi_3) \tag{13}$$

$$\frac{\partial F(y)}{\partial y}=(2y-1)*(C_3-\pi_1*x-\pi_2*x+\pi_3*x) \tag{14}$$

3.3 Evolutionary result analysis

Based on these calculations, the determinants det(J) and traces tr(J) for each equilibrium point are listed in Table 5.

If the trace of the Jacobian at the equilibrium point is zero, it is not an ESS. Since tr(J) of $D(x_0,y_0)$ is 0, it is not an ESS. As shown in Table 6, there are seven scenarios in the replicator system.

In Scenario 1, if $S_2-S_1-C_2+U_1-U_2<0$ and $\pi_1-C_3+\pi_2-\pi_3<0$, with $C_1+S_1-S_2-U_1+U_2>0$, for patients with malignant tumors, their benefits under the direct settlement for cross-regional medical treatment are greater than those for in-area medical care, whereas their benefits under the indirect settlement for cross-regional medical treatment are less than those in the insured area. Hospitals gain less from direct settlements than they do not implement them. The stable strategy is $(0,0)$, in which patients avoid cross-regional treatment, and hospitals choose not to implement the direct settlement policy. The evolutionary process is illustrated in Figure 1A.

In Scenario 2, if $S_2-S_1-C_2+U_1-U_2<0$, and $\pi_1-C_3+\pi_2-\pi_3<0$, with $C_1+S_1-S_2-U_1+U_2<0$, for patients with malignant tumors, the benefits under the direct settlement for cross-regional medical treatment are greater than those for in-area medical care. The benefits of indirect settlement for cross-regional medical treatment are more significant than those for insured areas. The stable strategy is $(0,0)$, in which patients avoid cross-regional treatment and hospitals choose not to implement the direct settlement policy. The evolutionary process is illustrated in Figure 1B.

In Scenario 3, if $S_2-S_1-C_2+U_1-U_2<0$, and $\pi_1-C_3+\pi_2-\pi_3>0$, with $C_1+S_1-S_2-U_1+U_2>0$, for patients with malignant tumors, the benefits under the direct settlement for cross-regional medical treatment are greater than those for in-area medical care. By contrast, their benefits under indirect settlement for cross-regional medical treatment are lower than those in their insured areas. The stable strategy is $(0,0)$, in which patients avoid cross-regional treatment and hospitals choose not to implement the direct settlement policy. The evolutionary process is illustrated in Figure 1C.

In Scenario 4, if $S_2-S_1-C_2+U_1-U_2<0$, and $\pi_1-C_3+\pi_2-\pi_3>0$, with $C_1+S_1-S_2-U_1+U_2<0$, for patients with malignant tumors, the benefits under the direct settlement for cross-regional medical treatment are greater than those for in-area medical care, and the benefits under the indirect settlement for cross-regional medical treatment are more significant than those in their

TABLE 5 Analysis results of local stability.

Equilibrium	$\det(J)$	$Tr(J)$
$O(0,0)$	$(S_2-S_1-C_2+U_1-U_2)(-C_3)$	$S_2-S_1-C_2+U_1-U_2-C_3$
$A(1,0)$	$(C_2+S_1-S_2-U_1+U_2)(\pi_1-C_3+\pi_2-\pi_3)$	$C_2+S_1-S_2-U_1+U_2+\pi_1-C_3+\pi_2-\pi_3$
$B(0,1)$	$(S_2-S_1-C_1+U_1-U_2)*C_3$	$S_2-S_1-C_1+U_1-U_2+C_3$
$C(1,1)$	$(C_1+S_1-S_2-U_1+U_2)(C_3-\pi_1-\pi_2+\pi_3)$	$C_1+S_1-S_2-U_1+U_2+C_3-\pi_1-\pi_2+\pi_3$
$D(x_0,y_0)$	No need to calculate	0

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TABLE 6 Stability analysis of evolutionary strategic portfolios.

Scenarioc	Requirements for establishment	Equilibrium point	$\det(J)$	$Tr(J)$	Stability
1	$S_2-S_1-C_2+U_1-U_2<0$ $\pi_1-C_3+\pi_2-\pi_3<0$ $C_1+S_1-S_2-U_1+U_2>0$	$(0,0)$	+	−	ESS
		$(1,0)$	−	Uncertain	Saddle point
		$(0,1)$	−	Uncertain	Saddle point
		$(1,1)$	+	+	Unstable
2	$S_2-S_1-C_2+U_1-U_2<0$ $\pi_1-C_3+\pi_2-\pi_3<0$ $C_1+S_1-S_2-U_1+U_2<0$	$(0,0)$	+	−	ESS
		$(1,0)$	−	Uncertain	Saddle point
		$(0,1)$	+	+	Unstable
		$(1,1)$	−	Uncertain	Saddle point
3	$S_2-S_1-C_2+U_1-U_2<0$ $\pi_1-C_3+\pi_2-\pi_3>0$ $C_1+S_1-S_2-U_1+U_2>0$	$(0,0)$	+	−	ESS
		$(1,0)$	+	+	Unstable
		$(0,1)$	−	Uncertain	Saddle point
		$(1,1)$	−	Uncertain	Saddle point
4	$S_2-S_1-C_2+U_1-U_2<0$ $\pi_1-C_3+\pi_2-\pi_3>0$ $C_1+S_1-S_2-U_1+U_2<0$	$(0,0)$	+	−	ESS
		$(1,0)$	+	+	Unstable
		$(0,1)$	+	+	Unstable
		$(1,1)$	+	−	ESS
5	$C_2+S_1-S_2-U_1+U_2<0$ $\pi_1-C_3+\pi_2-\pi_3<0$ $C_1+S_1-S_2-U_1+U_2>0$	$(0,0)$	−	Uncertain	Saddle point
		$(1,0)$	+	−	ESS
		$(0,1)$	−	Uncertain	Saddle point
		$(1,1)$	+	+	Unstable
6	$C_2+S_1-S_2-U_1+U_2<0$ $\pi_1-C_3+\pi_2-\pi_3<0$ $C_1+S_1-S_2-U_1+U_2<0$	$(0,0)$	−	Uncertain	Saddle point
		$(1,0)$	+	−	ESS
		$(0,1)$	+	+	Unstable
		$(1,1)$	−	Uncertain	Saddle point
7	$C_1+S_1-S_2-U_1+U_2<0$ $C_3-\pi_1-\pi_2+\pi_3<0$ $S_2-S_1+U_1-U_2-C_2>0$	$(0,0)$	−	Uncertain	Saddle point
		$(1,0)$	−	Uncertain	Saddle point
		$(0,1)$	+	+	Unstable
		$(1,1)$	+	−	ESS

insured area. The stable strategies are $(0,0)$ and $(1,1)$, indicating that patients avoid or choose cross-regional treatment and hospitals opt against or for implementing the direct settlement policy, respectively. The evolutionary process is illustrated in Figure 1D.

In Scenario 5, if $C_2+S_1-S_2-U_1+U_2<0$, and $\pi_1-C_3+\pi_2-\pi_3<0$, with $C_1+S_1-S_2-U_1+U_2>0$, for patients with malignant tumors, their benefits under the direct settlement for cross-regional medical treatment are less than those for in-area medical

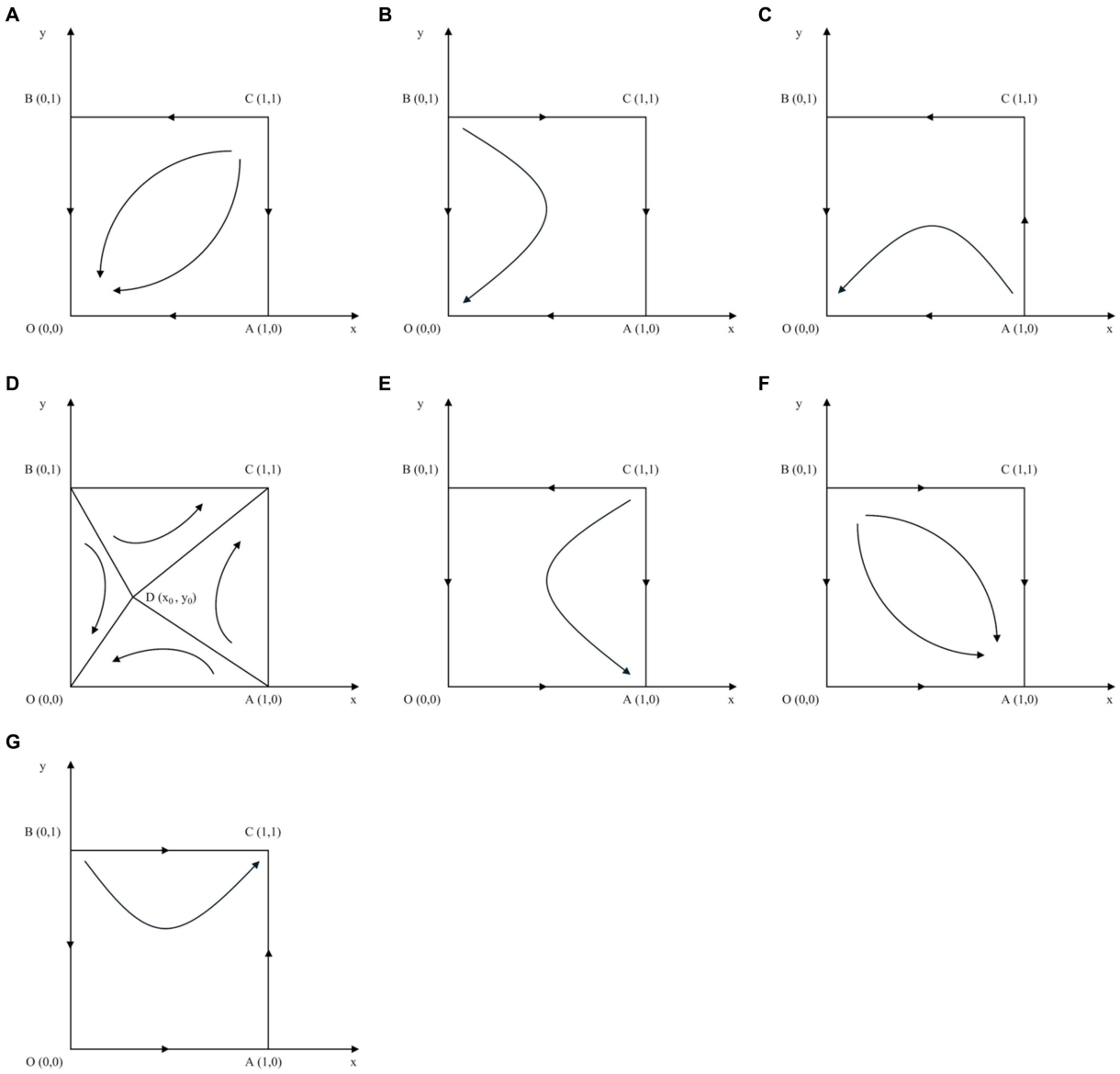


FIGURE 1
Phase diagram for the scenarios. **(A)** Scenario 1. **(B)** Scenario 2. **(C)** Scenario 3. **(D)** Scenario 4. **(E)** Scenario 5. **(F)** Scenario 6. **(G)** Scenario 7.

care, and their benefits under the indirect settlement for cross-regional medical treatment are less than those in their insured area. The stable strategy is $(1,0)$, in which patients choose cross-regional treatment and hospitals opt not to implement the direct settlement policy. The evolutionary process is illustrated in Figure 1E.

In Scenario 6, if $C_2 + S_1 - S_2 - U_1 + U_2 < 0$, and $\pi_1 - C_3 + \pi_2 - \pi_3 < 0$, with $C_1 + S_1 - S_2 - U_1 + U_2 < 0$, for patients with malignant tumors, their benefits under the direct settlement for cross-regional medical treatment are less than those for in-area medical care, while their benefits under the indirect settlement for cross-regional medical treatment are greater than those in their insured area. Hospitals gain less from direct settlements. The stable strategy is $(1,0)$, in which patients choose cross-regional treatment and hospitals opt not to implement a direct settlement policy. The evolutionary process is illustrated in Figure 1F.

In Scenario 7, if $C_1 + S_1 - S_2 - U_1 + U_2 < 0$, and $C_3 - \pi_1 - \pi_2 + \pi_3 < 0$, with $S_2 - S_1 + U_1 - U_2 - C_2 > 0$, for patients with malignant tumors, the benefits they receive under indirect settlement for cross-regional medical treatment are greater than those in their insured area. Moreover, the gap between the utility derived from cross-regional medical treatment and associated out-of-pocket medical expenses is larger than the analogous gap observed when receiving medical care in the insured region. Hospitals benefit less from a direct settlement. The stable strategy is $(1,1)$, meaning that patients choose cross-regional treatment, and hospitals implement a direct settlement policy. The evolutionary process is illustrated in Figure 1G.

4 Numerical simulations

4.1 Evolutionary stabilization strategy

Numerical simulations were conducted using MATLAB to study the strategic dynamics between patients with malignant tumors and hospitals.

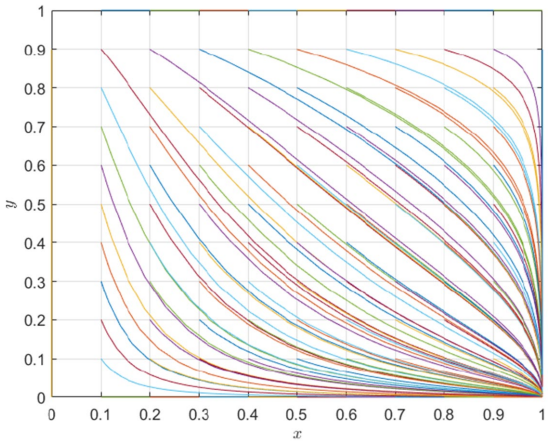


FIGURE 2
Simulation of parameters of the equilibrium point.

The parameters were set based on prior research hypotheses and relevant research. Following the assumptions of $\pi_1 > \pi_3$ and $\pi_2 > 0$, the values for patient medical cost coefficients were based on the research of Fu (51), Han (52), and Shang (53), leading to $\pi_1 = 7$, $\pi_2 = 2$, and $\pi_3 = 6$. Cost coefficients C_1 =0.5, $C_2 = 1$, and $C_3 = 4$ referring to Xie (26) and Li (54) were based on the assumptions $C_1 < C_2$ and $C_3 > 0$. Patient medical costs $S_1 = 3$ and S_2=4 were assigned following the assumption $S_1 < S_2$ and the findings of Wu (25) and Zheng (55). Finally, the utility coefficients $U_1 = 6$ and $U_2 = 4$ were determined based on Chen (56) and Gao (57), adhering to the hypothesis $U_1 > U_2$.

To ensure the generalizability of the numerical simulation findings, we used a comprehensive spectrum of simulations spanning a range of parameters from 0.1 to 1, progressing in increments of 0.1 (58). The analysis indicated an emerging scenario in which patients with malignant tumors choose cross-regional treatment, whereas hospitals tend not to adopt a direct settlement policy. This aligns with Scenarios 5 and 6 of the evolutionary game, leading to evolutionary convergence toward strategy $(1,0)$. A simulation-based analysis

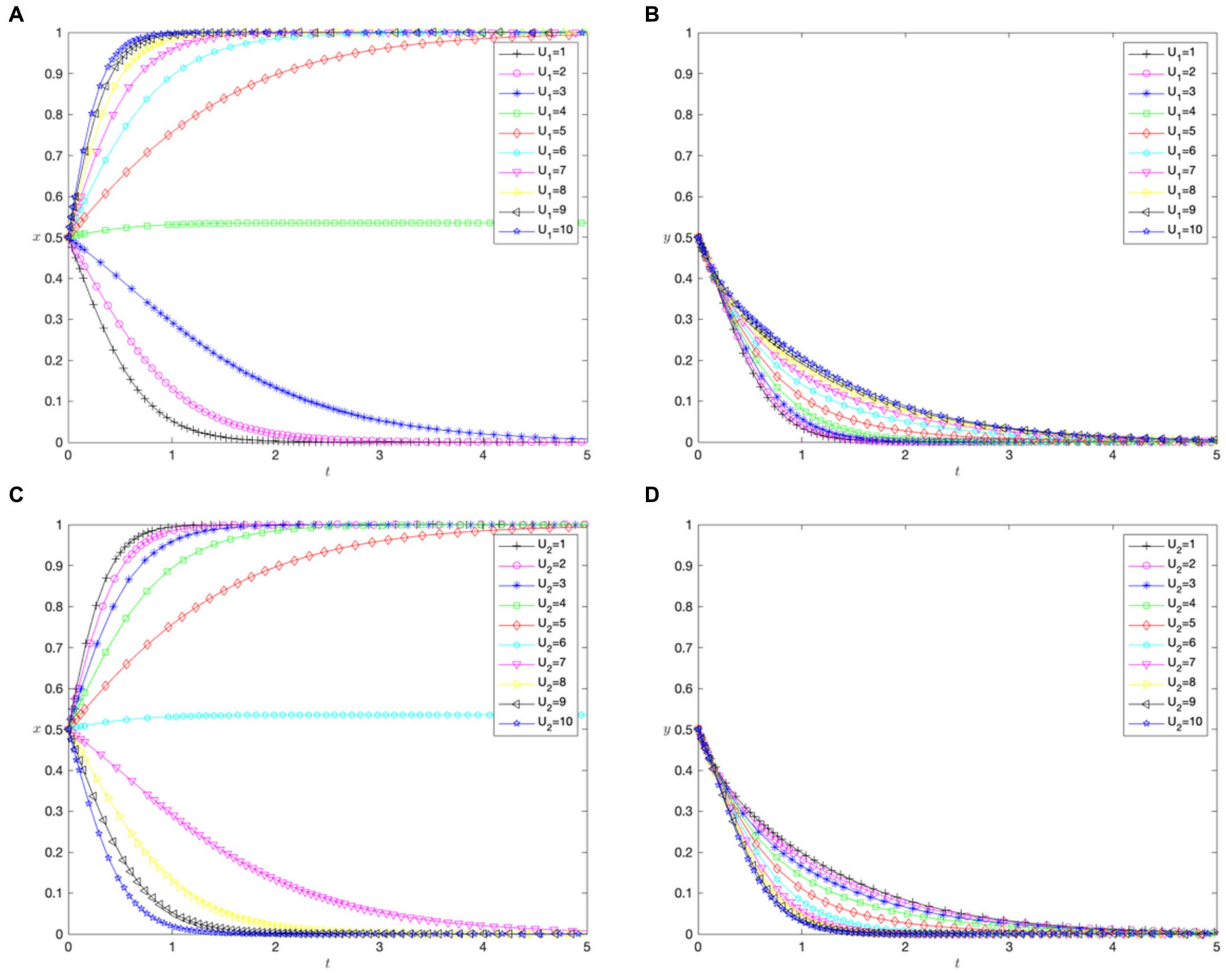


FIGURE 3
The impact of patient medical utility. **(A)** Impact of the utility of cross-regional treatment (U_1) on patients. **(B)** Impact of the utility of cross-regional treatment (U_1) on hospitals. **(C)** Impact of the utility of in-area medical care (U_2) on patients. **(D)** Impact of the utility of in-area medical care (U_2) on hospitals.

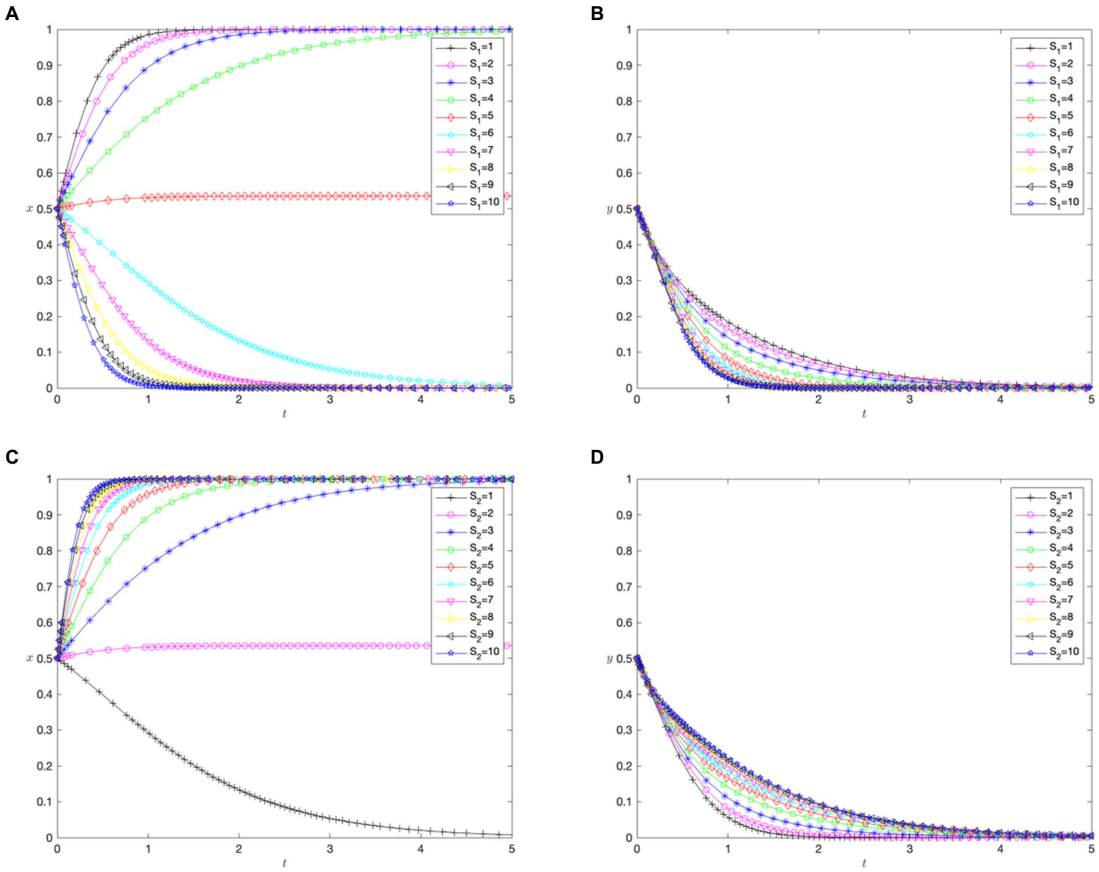


FIGURE 4
The impact of patient medical costs. **(A)** Impact of medical costs paid by patients after cross-regional treatment (S_1) on patients. **(B)** Impact of medical costs paid by patients after cross-regional treatment (S_1) on hospitals. **(C)** Impact of medical costs paid by patients after in-area medical care (S_2) on patients. **(D)** Impact of medical costs paid by patients after in-area medical care (S_2) hospitals.

conducted with varying parameters corroborated the sixth scenario of the game. Additionally, the evolution rate varied with different initial values, but the outcome remained unchanged, indicating that the change in the initial values did not affect the stability determination condition. As shown in Figure 2, the optimal strategy for patients with malignant tumors is "cross-regional treatment," while the optimal strategy for hospitals is "indirect settlement."

4.2 Parameter sensitivity analysis

4.2.1 The impact of patient medical utility

Figures 3A,B show the impact of the utility coefficient for patients' cross-regional treatment on their choice of treatment location and the hospital cross-regional settlement policy. When the utility coefficient U_1 is low, patients with malignant tumors typically opt for medical care within their region. However, as U_1 increases to five, their evolutionarily stable strategy shifts toward cross-regional treatment due to heightened utility, making treatment in other areas more advantageous. Irrespective of the variations in U_1, hospitals determine that the optimal strategy is not to implement a cross-regional settlement policy.

Figures 3C,D show the impact of the utility coefficient for in-area medical care (U_2) on patients' choice of treatment location and cross-regional hospital settlement policies. In contrast to the utility coefficient for cross-regional treatment (U_1), a lower U_2 value indicates that patients with malignant tumors prefer cross-regional treatment. When U_2 increased to seven, the evolutionarily stable strategy shifted to in-area medical care. This suggests that increases in the utility of in-area care influence patients' choices more sensitively than those of cross-regional care. Similar to the effects of U_1, regardless of the variations in U_2, the optimal strategy for hospitals is not to implement a direct settlement policy for cross-regional treatment.

4.2.2 The impact of patient medical costs

Figures 4A,B demonstrate how the coefficient of medical costs paid by patients for cross-regional treatment (S_1) affects the patients' choice of treatment location and hospital cross-regional settlement policies. With a lower S_1, patients with malignant tumors favor cross-regional treatment. As S_1 increased to 6, their preference shifted to in-area medical care. However, S_1 did not impact hospitals' settlement policies, and not implementing direct settlement remained the best strategy.

Figures 4C,D demonstrate how the coefficient of the medical costs paid by patients for in-area treatment (S_2) affected their choices. When S_2 is 1, the patients opt for in-area medical care. As S_2 increases, they lean toward cross-regional treatment. The rate of change in S_2 compared with S_1 suggests a higher sensitivity to in-area treatment costs. Despite varying S_2, hospitals chose not to implement direct cross-regional settlements.

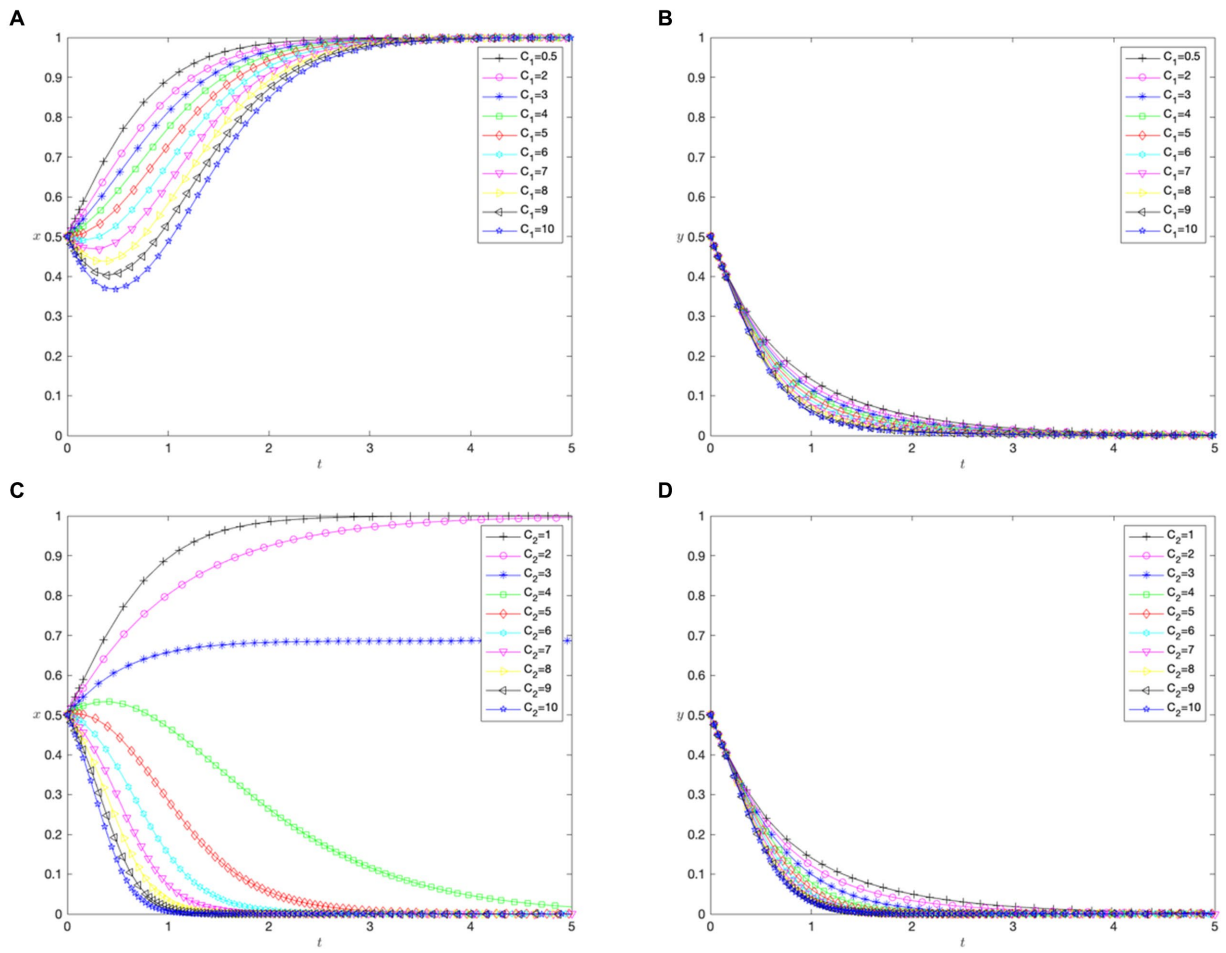


FIGURE 5
The impact of other costs of cross-regional treatment for patients. **(A)** Impact of other costs of cross-regional treatment with direct settlement (C_1) on patients. **(B)** Impact of other costs of cross-regional treatment with direct settlement (C_1) on hospitals. **(C)** Impact of other costs of cross-regional treatment without direct settlement (C_2) on patients. **(D)** Impact of other costs of cross-regional treatment without direct settlement (C_2) on hospitals.

4.2.3 The impact of other costs of cross-regional treatment for patients

Figures 5A,B highlight the impact of the coefficient of other costs under direct settlement (C_1) on the choice of treatment location by patients and the cross-regional settlement policies of hospitals. As the value of C_1 increased, patients consistently chose cross-regional treatment, and hospitals opt not to settle directly for cross-regional treatments.

Figures 5C,D highlight the effect of the coefficient of other costs without direct settlement (C_2) for cross-regional treatment on similar choices. When C_2 ranged from 1 to 3, patients were more likely to choose cross-regional treatment. However, as C_2 increased, they switched to in-area medical care. In response to changes in C_2, hospitals maintain a strategy of not directly settling for cross-regional treatment.

4.2.4 The impact of hospital benefits from cross-regional treatment

Figures 6A,B reveal how the financial benefit coefficient (π_1) for hospitals offering cross-regional treatment affects patients' choice of treatment location and hospital settlement policies. As π_1 increases, patients consistently choose cross-regional treatment, indicating that hospitals' financial gains from such treatment do not affect their choices. However, hospitals tended to shift from implementing a direct settlement policy to implementing it.

Figures 6C,D reveal how the technological advancement benefit coefficient (π_2) for hospitals affects choices. An increase in π_2 leads to patients' consistent preference for cross-regional treatment, showing that hospitals' technological advancement benefits from cross-regional treatment do not affect patients' choices. However, hospitals tended to shift from implementing the direct settlement policy to not implementing it, with a higher rate of change than π_1 , indicating a more substantial impact on hospital policies.

Figures 6E,F reveal how the financial benefit coefficient (π_3) for hospitals not implementing direct settlement affects choices. Increasing π_3 results in patients always choosing cross-regional treatment, suggesting that hospitals' technological advancement benefits do not influence patients' choices. However, hospitals' strategies changed from implementing to not implementing the direct settlement policy, opposite to the trend seen with π_1 .

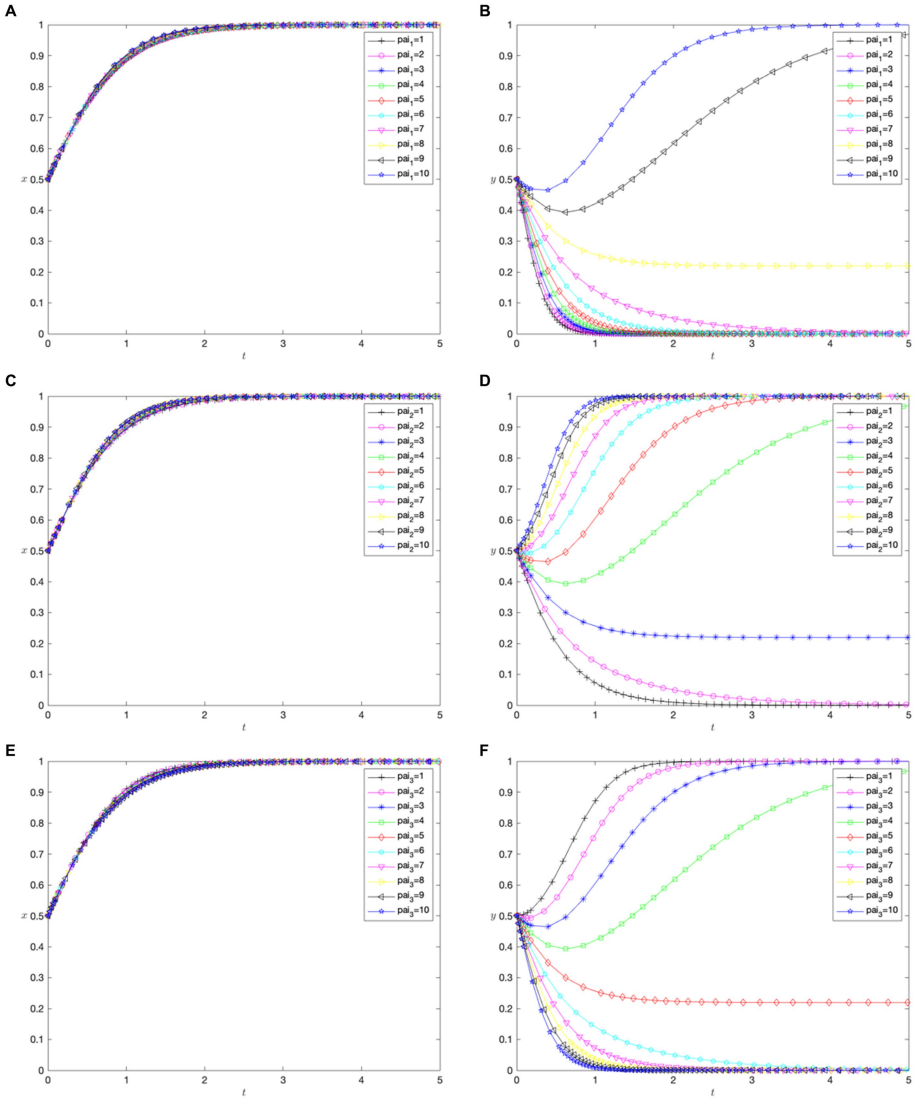


FIGURE 6
The impact of hospital revenues from cross-regional treatment. **(A)** Impact of financial benefits of implementing direct settlement for cross-regional treatment (π_1) on patients. **(B)** Impact of financial benefits of implementing direct settlement for cross-regional treatment (π_1) on hospitals. **(C)** Impact of technological advancement benefits of implementing direct settlement for cross-regional treatment (π_2) on patients. **(D)** Impact of technological advancement benefits of implementing direct settlement for cross-regional treatment (π_2) on hospitals. **(E)** Impact of financial benefits of implementing direct settlement for local treatment (π_3) on patients. **(F)** Impact of financial benefits of implementing direct settlement for local treatment (π_3) on hospitals.

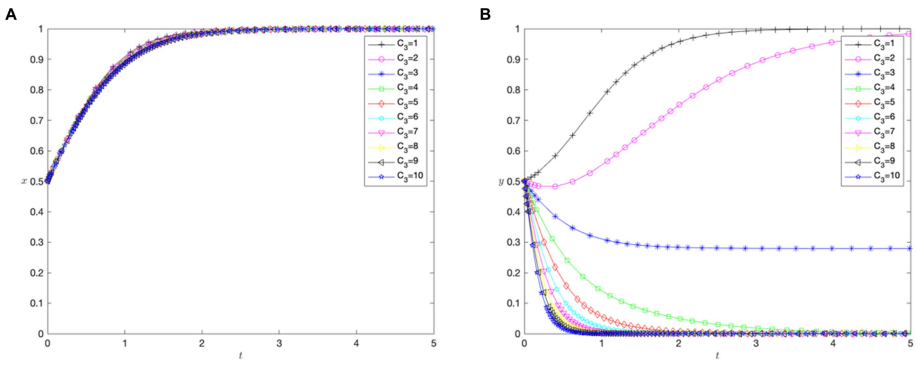


FIGURE 7
The impact of hospital costs for cross-regional treatment. **(A)** Impact of input costs of implementing direct settlement for cross-regional treatment (C_3) on patients. **(B)** Impact of input costs of implementing direct settlement for cross-regional treatment (C_3) on hospitals.

4.2.5 The impact of hospital costs for cross-regional treatment

Figures 7A,B depict the impact of the input cost coefficient (C_3) for hospitals implementing direct settlement in cross-regional treatment on patients' choice of treatment location and hospital settlement policies. When C_3 increases, the patients opt for cross-regional treatment, indicating that hospital operational costs did not directly affect their choices. Hospitals are more likely to implement direct settlement when C_3 is low but become reluctant when C_3 rises above 4.

5 Discussion and implications

5.1 Discussion

Driven by the pursuit of high-quality medical resources and additional considerations, patients with malignant tumors require cross-regional treatment; however, hospitals lack the motivation to implement direct settlement policies. The evolutionary game model in this study has seven scenarios, with four involving patients choosing cross-regional treatment and only two in which hospitals opt for direct settlement. The simulation analysis shows that the evolutionary game results correspond to Scenario 6, described earlier, where the optimal strategy for patients is cross-regional treatment, whereas it does not implement direct settlement for hospitals. Regardless of changes in the patient's utility (U_1 and U_2), medical costs (S_1 and S_2), and other costs of the patient's cross-location medical treatment (C_1 and C_2), the hospital's gaming strategy did not change. This indicates that whether the hospital executes a direct settlement policy is not affected by the patient's benefit in the game between the two sides. In addition, the two parties only cooperate in the seventh scenario in the stability analysis; that is, the patient chooses to seek cross-regional treatment and the hospital implements a direct settlement policy. The conditions for realizing this scenario were $C_1 + S_1 - S_2 - U_1 + U_2 < 0$, $C_3 - \pi_1 - \pi_2 + \pi_3 < 0$, and $S_2 - S_1 + U_1 - U_2 - C_2 > 0$. However, meeting these conditions is challenging, and the lack of effective incentives for hospitals to implement direct settlement policies explains why the current cross-regional treatment policies are not as widespread as anticipated (11).

The key factors influencing the willingness of some patients with malignant tumors include the costs of in-area medical care, costs of cross-regional treatment without direct settlement, and the utility of cross-regional treatment. A comparison of the impact of various parameters on the evolutionary outcome reveals that parameters with fast convergence rates and short convergence times included the medical costs paid by patients after in-area medical care (S_2), other costs of cross-regional treatment without direct settlement (C_2), and the utility of cross-regional treatment (U_1). First, Patients with malignant tumors are sensitive to changes in in-area medical care costs because their medical expenses are high. Between 2012 and 2014, the average medical expenses for these patients in China were approximately $ 10,000 (59), whereas the average medical expenses for general patients were approximately $ 1,000 (60). Thus, medical expenses for patients with malignant tumors are significantly high. The cross-regional settlement follows the principle of "insurance catalog of the treatment location and reimbursement standards of the insured site." Under the same treatment standards, some patients often receive more medical service reimbursements, such as reimbursements for targeted drugs, in cross-regional hospitals with sufficient medical insurance coverage, such as reimbursements for targeted drugs (27). Under settlements based on the medical insurance catalog of the treatment location, actual expenses are often lower than those for in-area treatment (23). Furthermore, patients with malignant tumors are highly sensitive to the indirect settlement costs associated with cross-regional treatment. This is because their condition requires long-term and extensive treatment, with a propensity for recurrence or metastasis, necessitating frequent diagnosis, treatment, and follow-up (61). Factors such as travel and accommodation expenses, as well as efforts during cross-regional medical visits greatly influence treatment decisions (62). The absence of direct insurance settlements in cross-regional hospitals further increases these costs. Moreover, patients are sensitive to cross-regional treatment owing to the high mortality rate associated with malignant tumors. In China, the five-year relative survival rate of patients with malignant tumors is approximately 40.5% (16). Therefore, patients tend to seek medical care to achieve better treatment outcomes.

Therefore, patients with malignant tumors could adopt the following strategies. From the perspective of medical utility (U_1 and U_2), patients with high mortality and low mortality tumors should have different strategies. Patients with high mortality cancers such as pancreatic cancer, liver cancer, lung cancer, and esophageal cancer (63) should consider traveling to regions with more developed medical resources to get better five-year survival rates. For patients with low mortality cancers, such as breast cancer, prostate cancer, thyroid cancer, and melanoma (63), the medical utility of local treatment is similar to that of treatment in other regions due to mature treatment methods and standardized diagnostic and treatment guidelines. And staying local for treatment can also save on the additional costs associated with cross-regional treatment. Regarding medical costs(S_1 and S_2), the treatment expenses for patients in the surgical phase are significantly lower than for those requiring chemotherapy, targeted therapy, or immunotherapy (64, 65), thus local treatment is advisable for patients in the surgical phase. Non-surgical patients, in search of better health insurance reimbursement policies, might choose to travel to regions with a broader coverage of health insurance. Considering the indirect costs of cross-regional treatment without direct settlement (C_2), patients with malignant tumors who do not require immediate surgery or emergency care could use telemedicine services, such as video consultations or telephone medical advice, to minimize the need for travel.

Hospitals' motivations to implement direct settlement policies are influenced by two main factors: technological advancement benefits and input costs. A comparison of the impact of different parameters shows that the parameters with fast convergence rates and short convergence times include the technological advancement benefits of implementing direct settlement for cross-regional treatment (π_2), and the input costs of implementing direct settlement for cross-regional treatment (C_3). The simulation analysis confirms that the convergence of technological advancement benefits for hospitals is faster than that of their financial benefits. This can be attributed to the shift in focus of China's public hospitals toward high-quality and substantive development, with sustainable operational capabilities and the construction of clinical specialties becoming key priorities in hospital development (66). This aligns with the direct settlement policy for cross-regional treatment as it provides hospitals with more elements of demand from a resource allocation perspective. This policy enables hospitals to identify patients with urgent treatment needs and higher disease complexity for diagnosis and treatment (67).

However, before implementing a cross-regional treatment policy, hospitals must revamp their information systems and ensure sufficient operational costs for patient policy education, medical insurance reimbursements, and analysis. Consequently, the input costs for hospitals in direct settlements for cross-regional treatment are relatively high, which affects their willingness to implement this policy.

Therefore, hospitals could employ several strategies. First, based on their financial health, hospitals should rigorously assess the investment costs associated with implementing direct settlement systems (C_3), which includes expenses related to upgrading information systems, patient education, and handling of medical insurance reimbursements. For financially robust and well-staffed hospitals, it is advisable to seek qualification for direct settlements, facilitating more convenient services for patients undergoing treatment for malignant tumors from different regions. Conversely, hospitals with constrained financial resources should prioritize the care of potential malignant tumor patients within their jurisdiction. Secondly, considering the advantages of technological advancements (π_2) and patient medical utility (U_1 and U_2), tertiary regional hospitals should invest in the latest medical equipment and technologies, such as PET-CT scanners and advanced radiation therapy devices, to provide precise diagnostics and treatments. These hospitals should also establish multidisciplinary treatment teams to manage patient care comprehensively and prioritize the creation of day clinics and treatment centers to enable patients from various locations to receive radiotherapy and chemotherapy in the shortest possible time (68). Other hospitals may establish cooperative medical networks or offer telemedicine services, leveraging regional hospitals' expertise and diagnostic capabilities to provide necessary treatments and consultations. Finally, all hospitals should optimize internal diagnostics, treatments, examinations, and report delivery processes, reducing waiting times for patients with malignant tumors. This optimization helps to mitigate the additional costs associated with medical appointments, such as expenses for offsite accommodations, family caregiving, and loss of income due to work interruptions.

5.2 Theoretical implications

We developed a behavioral analysis framework that classifies patients with malignant tumors and hospitals into two groups, offering theoretical validation for actual scenarios. In dissecting the treatment-seeking behavior associated with cross-regional settlement methods, we validated the urgent medical needs of cross-regional patients and the limited motivation of hospitals for cross-regional direct settlement. We identified the key factors that enhance cooperation between the two parties, thereby validating and clarifying the realities of cross-regional treatment in China. The analytical framework intentionally omits the impact of existing policies, which paradoxically lends theoretical support to the development of new direct settlement policies for cross-regional medical treatment.

Additionally, the incorporation of game theory into our research methodology has significantly augmented the analytical depth of studies on cross-regional treatment. Confronted with a scarcity of empirical data, our reliance on game-theoretic paradigms amplifies the interpretative robustness of our findings. The bounded rationality inherent in the Evolutionary Game Theory is more congruent with the real-world dynamics of cross-regional treatment and the execution of hospital policies. Furthermore, the dynamic development perspective of the Evolutionary Game Theory compensates for potential short-term strategic behaviors between patients and hospitals in cross-regional contexts. This method led to a more accurate and comprehensive exploration of interactions between the two groups.

Moreover, this study, which is centered on the Chinese context, injects novel perspectives into global research. With the burgeoning demand for cross-regional treatment worldwide (69), as evidenced in nations such as the United States (70), the EU (71), Russia (72), and India (73), our study enriches scholarly research on China's cross-regional treatment dynamics. It can provide valuable insights on a global scale for regions grappling with the limitations of geographic coverage in medical insurance coordination, inadequate health insurance reimbursement for non-local treatments, and the high demand for cross-regional medical services among patients with malignant tumors. For example, in Brazil, despite the government's promotion of fluvial mobile units, the remote Amazon region still faces severe shortages in medical services and insurance coverage (74); in the Philippines, although the PhilHealth insurance system is in place, patients in provinces outside the capital region, especially on the more distant islands, often face medical expenses that exceed insurance coverage (75); in Italy, particularly between the north and the south, the uneven distribution of medical resources leads many cancer patients from the southern regions to seek more advanced treatments in northern cities like Milan or Turin (76); in Thailand and Cuba, the thriving health tourism sector, known for quality and affordability, draws international patients for advanced treatments like cardiac and cosmetic surgeries (77).

5.3 Policy implications

To promote a risk-sharing mechanism between the treatment location and the insurance registration location, and to ensure that tertiary hospitals offer direct settlement services. Local health insurance management departments should proactively implement policies for offsite medical treatment and direct settlement, incorporating a risk-sharing mechanism between the treatment and insurance registration locations to share the excess medical costs incurred by patients seeking offsite treatment, thus incentivizing the insurance department at the treatment location to enforce regulations. Moreover, with the promotion of direct settlement policies, it is essential to consider the disparities in medical service accessibility across various provinces and cities caused by the household registration system. High-level tertiary hospitals should take the initiative to qualify for offsite medical treatment direct settlement, whereas weaker first- and second-level hospitals should be phased out gradually. This ensures that patients from different locations receive the appropriate treatment at high-level hospitals.

Moreover, by enhancing the provincial level of medical insurance pooling and exploring the adoption of the Diagnosis-Related Group (DRG) and Diagnosis Intervention Packet (DIP), strides can be made to augment the healthcare system's effectiveness. Achieving nationwide health insurance coordination within a short timeframe is not realistic because of disparities in the three-level catalogs and drug codes across different regions in China. Therefore, the primary focus should be gradually improving provincial health insurance coordination and establishing consistent settlement standards for medical treatments within the same province. Besides, due to the current fee-for-service payment model adopted for medical insurance in cross-regional medical treatments, hospitals are more inclined to admit patients from other regions, resulting in disparities in healthcare access between local and

non-local patients (12). To address this issue, it is proposed to initiate reforms in hospitalization expense management by implementing a trial of both the DRG and DIP with monthly pre-settlement and annual clearing modes can be introduced. This strategy will incentivize hospitals to make more considered diagnoses and treatment decisions, enhance equity in access to medical resources, and ultimately improve the overall quality of healthcare services.

Using digital health technologies to significantly enhance remote initial diagnostic capabilities and promotes collaborative diagnostics and treatments across healthcare regions. Through internet-based medical platforms, physicians can provide remote initial consultations for malignant tumor patients seeking care outside their local facilities. These consultations facilitate preliminary symptom assessment and guide patients on whether they should seek further examinations or treatments at higher-level hospitals. Additionally, these technologies are instrumental in implementing post-treatment follow-ups and continuous health monitoring. This approach not only alleviates unnecessary patient travel and financial expenditures but also significantly reduces the wastage of medical resources. Simultaneously, the establishment of cross-regional medical consortia is imperative (78). Such consortia facilitate the sharing of medical records among hospitals across different regions and foster professional discussions and collaborations, ensuring that patients receive standardized, high-quality diagnostic and treatment services even when away from their insured location.

It is important to note that the implementation of these strategies varies among different regions and hospitals, with some areas facing greater challenges due to economic, resource, or management disparities. This interplay between regions and hospitals can impact the uniform implementation and effectiveness of policies, necessitating more customized and regional strategies to address these challenges.

5.4 Limitations and future work

This study enriches the academic discussion on cross-regional medical treatment from a Chinese perspective, showing significant theoretical value. However, there are several noteworthy limitations in the study. Firstly, due to challenges in obtaining empirical data and insufficient funding, this study uses Evolutionary Game Theory to theoretically explore the interaction strategies between the medical behaviors of patients with malignant tumors and settlements in some hospitals. This approach is close to reality but not entirely based on actual situations. Furthermore, the analysis based on the technically complex Evolutionary Game Theory is difficult for the general readership to understand. Therefore, future research could, on the one hand, propose new hypotheses based on the results of this model, collect empirical data for analysis to enhance the real-world applicability of the research; on the other hand, conduct case studies to deeply explain the conclusions of the evolutionary game model, enhance the implementation of policy recommendations, and improve understanding among policymakers and practitioners. Secondly, the model used in this study simplifies and abstracts the complex interaction system between patients with malignant tumors and some hospitals, providing valuable insights into the balance of interests between hospitals and patients. However, it fails to capture the complexity of real-world issues fully, which may lead to overly generalized conclusions. For example, it does not consider differences in hospital levels or the subtle differences in direct settlement policies across different provinces. Future research should explore these factors to deepen understanding of the issue. Thirdly, the COVID-19 pandemic disrupted the provision and access to healthcare services (79). Although retrospective studies on the cross-regional settlement of patients with malignant tumors may seem less relevant in the post-pandemic era from today's perspective, such research is still extremely valuable from the perspective of medical service fairness. It not only helps to understand how the pandemic has exacerbated medical inequalities for specific groups but also provides an essential basis for formulating fairer and more effective health policies in potential future crises.

6 Conclusion

Cross-regional medical treatment has become necessary in response to the insufficient distribution of high-quality medical resources. The localized management of medical insurance in China is actively improving the accessibility and convenience of medical services through direct settlement services. Patients with malignant tumors, the leading group seeking cross-regional treatment, face significant financial burdens. Based on this, this study presents an evolutionary game model between patients with malignant tumors and some hospitals, analyzing the optimal strategies, stability of strategy combinations, and interrelations of influencing factors. This theoretical framework provides a deeper understanding of this issue. This study proposes potential measures to draw further attention to the issue of cross-regional medical settlements in China.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

XZ: Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing. LL: Writing – review & editing. DZ: Conceptualization, Methodology, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Toripalimab plus chemotherapy in the treatment of metastatic triple-negative breast cancer: a cost-effectiveness analysis

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Objective: This study focuses on assessing the cost-effectiveness of incorporating toripalimab alongside chemotherapy for the treatment of patients diagnosed with metastatic triple-negative breast cancer from the perspective of the Chinese healthcare system.

Methods: A partitioned survival model was constructed to simulate the costs and health outcomes over the lifetime of patients with mTNBC. Clinical data regarding overall survival, progression-free survival, and treatment-related adverse events were derived from the TORCHLIGHT clinical trials. Incremental cost-effectiveness ratio (ICER) were calculated based on the gains in quality-adjusted life-year (QALY). The willingness-to-pay (WTP) threshold was defined as $39,855.79 per QALY. Additionally, sensitivity analyses were conducted to examine the robustness of the model.

Results: The total cost incurred by the group receiving toripalimab was $38,040.62, while the placebo plus chemotherapy was $26,102.07. The utilization of the toripalimab regimen resulted in an increase of 0.74 QALYs and an incremental cost of $11,938.55 compared to the placebo plus chemotherapy group. The ICER was $16,133.18/QALY, indicating that toripalimab plus chemotherapy is a cost-effective strategy according to the WTP threshold. Sensitivity analyses confirmed the robustness of the results.

Conclusion: This study suggests that the addition of toripalimab to chemotherapy for the treatment of mTNBC is a cost-effective strategy. The findings provide valuable evidence to guide decision-making regarding treatment selection for patients with mTNBC in China.

KEYWORDS

metastatic triple-negative breast cancer, toripalimab, chemotherapy, cost-effectiveness analysis, partitioned survival model

1 Introduction

Breast cancer stands as the most prevalent form of cancer among women, with a global tally of 2,308,897 new cases in 2022, constituting 11.6% of all newly diagnosed tumors and ranking second amongst all cancer types (1). Triple-negative breast cancer (TNBC) is a highly concerning subtype of breast cancer that is characterized by the absence of key receptors, including the estrogen receptor (ER), progesterone receptor (PR), and human epidermal growth factor receptor 2 (HER2) (2). This specific feature poses a significant clinical challenge as it limits the availability of specific therapeutic targets, beyond the conventional chemotherapy treatment approach.

Despite accounting for only 15–20% of all breast cancers, TNBC has been associated with the poorest prognosis compared to other breast cancer subtypes (3). Systemic chemotherapy regimens that include taxanes and platinums have traditionally been considered the gold standard first-line treatment for TNBC before the advent of immunotherapy (4). However, despite the diligent efforts in treatment strategies, the median overall survival for individuals diagnosed with metastatic TNBC (mTNBC) remains dishearteningly low. Moreover, it is crucial to emphasize that the present 5-year survival rate for TNBC stands at a mere 12% (5), underscoring the pressing requirement for innovative therapeutic interventions capable of adequately tackling this substantial unmet medical demand.

In recent years, the advent of immunotherapy has brought about renewed hopes for enhancing treatment outcomes in TNBC (6, 7). One of the groundbreaking immunotherapy strategies in TNBC involves the use of immune checkpoint inhibitors (ICIs). These inhibitors target key molecules, such as programmed cell death protein 1 (PD-1) and programmed death-ligand 1 (PD-L1), that regulate immune responses and prevent excessive immune activation. By blocking these checkpoints, immune checkpoint inhibitors restore and enhance anti-tumor immune responses, leading to improved control and eradication of cancer cells. In the IMpassion130 trial, the combination therapy of atezolizumab and nab-paclitaxel was found to significantly extend the duration of time progression-free survival (PFS) in both the subgroup of patients with positive expression of the PD-L1 protein and in the overall study population (8). Similarly, the KEYNOTE-355 study demonstrated that pembrolizumab, when used in combination with chemotherapy, resulted in significant improvements in both PFS and overall survival (OS) compared to chemotherapy alone. These improvements were specifically observed in TNBC patients with a combined positive score (CPS) of PD-L1 expression $\geq$10 (9). These important clinical trials provide strong evidence supporting the use of immunotherapy in combination with chemotherapy as an effective therapeutic approach for TNBC patients.

Recently, Jiang et al. conducted a significant multicenter, randomized, double-blind phase 3 trial, referred to as TORCHLIGHT, which evaluated the efficacy of combining toripalimab and nab-paclitaxel compared to placebo plus chemotherapy in patients with mTNBC (10). The use of toripalimab, a novel immune checkpoint inhibitor, in combination with nab-paclitaxel provided a rationale for investigating the potential synergistic effects of this therapy. The median PFS was observed to be 8.4 months in the experimental arm, while it was 5.6 months in the control arm. Furthermore, this combination therapy also showed a notable improvement in median overall survival, with a median OS of 32.8 months in the experimental arm compared to 19.5 months in the control arm. This study demonstrated a significant improvement in median progression-free survival (mPFS) by 2.8 months in the experimental group, along with a notable 35% decrease in the risk of disease progression or mortality. Additionally, a descriptive analysis of OS indicated a favorable trend in both the PD-L1-positive and intention-to-treat (ITT) populations. Importantly, the incidence of treatment-emergent adverse events (AEs) in the experimental arm was comparable to that in the control arm, indicating that the addition of toripalimab to nab-paclitaxel did not significantly increase the risk of side effects. These findings suggest that the inclusion of toripalimab in the treatment regimen holds promise for PD-L1-positive patients with mTNBC, as it leads to a significant enhancement in PFS and potentially prolongs overall survival.

However, despite the encouraging initial findings, there is a notable dearth of comprehensive evaluations concerning the cost-effectiveness of the combination therapy involving toripalimab and nab-paclitaxel in comparison to chemotherapy administered as a standalone treatment. Considering the limited treatment alternatives and the potential for enhanced outcomes associated with the use of toripalimab in mTNBC, it becomes crucial to gain a better understanding of the cost-effectiveness of this intervention. In this study, our objective is to scrutinize the incremental cost-effectiveness ratio (ICER) of toripalimab plus nab-paclitaxel when contrasted with chemotherapy administered as the sole treatment. This analysis will furnish vital information regarding the additional expenses incurred to achieve an additional unit of health benefits. The findings generated from this investigation will not only provide valuable insights for healthcare practitioners and policymakers but also facilitate resource allocation decisions and contribute to the optimal management of this disease.

2 Methods

2.1 Model establish

To evaluate the cost-effectiveness of toripalimab, we utilized a partitioned survival model (PSM) to accurately simulate the progression of the disease and treatment outcomes over a 10-year time horizon for mTNBC. Our PSM categorizes patients into three distinct and mutually exclusive states: progression-free disease (PFD), progressive disease (PD), and death (Figure 1).

In order to align with the duration observed in the TORCHLIGHT clinical trial, we implemented a simulation cycle period of 21 days. All expenses associated with this study were converted into US dollars (USD) by utilizing the average exchange rate from RMB (Ren min Bi) to USD in the preceding year (2023), which stood at 100 USD per 705 units of RMB (11).

In line with established economic evaluation frameworks, we considered a willingness-to-pay (WTP) threshold of $39,855.79 per QALY according to the latest <<The China Guidelines for Pharmaceutical Economics Evaluation 2020>> as a significant criterion in China. This threshold holds particular significance as it is set at three times the national gross domestic product (GDP) for the year 2023 (12). By incorporating the WTP threshold, our intervention's cost-effectiveness was assessed by evaluating the incremental cost per additional QALY gained. The construction of the PSM was accomplished through the utilization of the TreeAge Pro 2011 software application.

2.2 Model population and treatment

The present model posits the underlying assumption that the target population under investigation exhibits a congruous

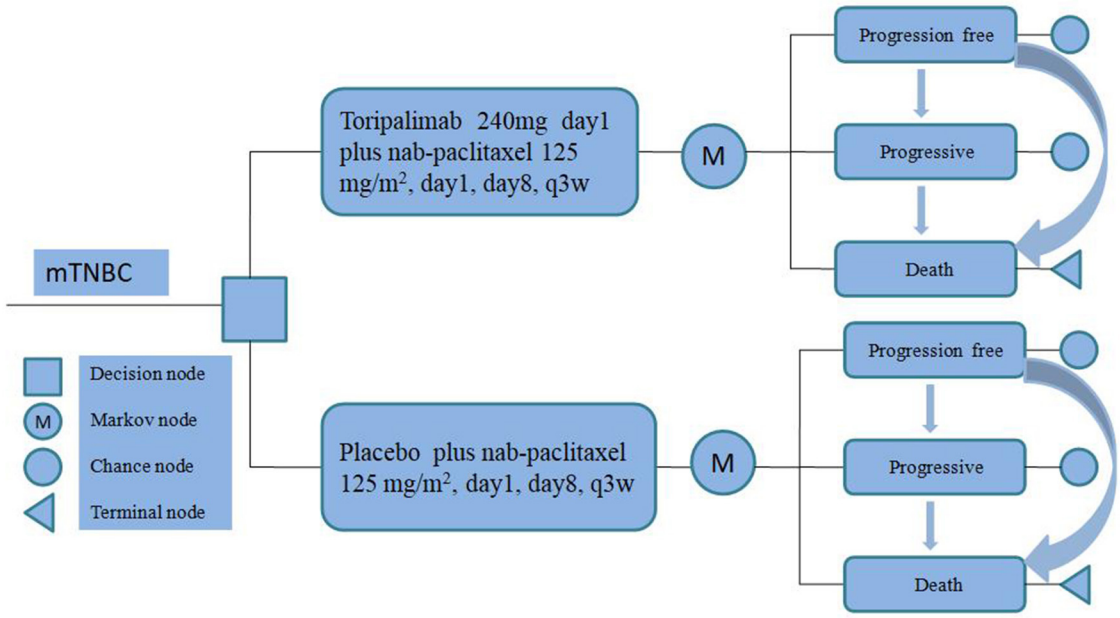


FIGURE 1
Partitioned survival model.

composition of participants as that observed within the TORCHLIGHT trial. A total of 353 female patients were randomly assigned to the experimental arm, while 178 patients were assigned to the control arm. All participants in this study were of Asian ethnicity and had a median age of 53 years (ranging from 23 to 84 years) and 54.5 years (ranging from 27 to 76 years) in the toripalimab and placebo plus chemotherapy groups, respectively. The allocation of patients based on their PD-L1 expression levels was evenly distributed between the two treatment groups. Specifically, 30.6 and 34.8% of patients in the toripalimab and placebo plus chemotherapy groups, respectively, exhibited PD-L1 CPS expression levels below 10. Moreover, 26.1 and 21.3% of patients in the toripalimab and placebo plus chemotherapy groups, respectively, demonstrated PD-L1 CPS expression levels of 10 or higher.

Participants will be subject to random allocation for administration of either toripalimab (240 mg, day 1) in conjunction with nab-paclitaxel (125 mg/m^2, day 1, day 8) every 3 weeks or a placebo plus chemotherapy in combination with nab-paclitaxel until the point of disease progression or the occurrence of intolerable adverse effects.

In order to enhance the efficiency of the modeling process, the current study primarily focuses on examining and comparing grade 3 or 4 adverse events that manifest at a frequency surpassing 4% in the cohorts.

In the toripalimab group, the median duration of therapy for the treated population was 21.14 (0.14–129.42) weeks, while in the placebo plus chemotherapy group, it was 22.14 (0.14–125.57) weeks. A total of 74 patients (21.0%) in the toripalimab cohort and 38 patients (21.3%) in the placebo plus chemotherapy cohort received subsequent anticancer therapy. In order to conduct a cost-effectiveness analysis, we made the assumption of using a second-line treatment consisting of gemcitabine plus carboplatin chemotherapy regimen for both treatment groups. However, considering the significant uncertainty surrounding the optimal choice of third-line therapy, our study assumes the utilization of the best supportive treatment regimen in case of disease re-progression.

2.3 Clinical transfer probability data extraction

In this study, we have conducted a rigorous analysis of the data acquired from the TORCHLIGHT clinical trial, utilizing the widely recognized data extraction tool GetData Graph Digitizer software. The primary aim of this study was to meticulously extract and subsequently model the survival curves, encompassing both overall survival and disease-free survival measures, by employing a rigorous process of identifying the statistically optimal distributions for these variables.

To determine the optimal Data reconstruction and best-fit survival curves, we employed a combination of two fundamental principles. Firstly, we employed the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) as the minimum statistical criteria (13). These statistical criteria enabled us to evaluate the goodness-of-fit of various distributions to the data and determine the most suitable models. The AIC and BIC values associated with the simulated survival curves can be found in Supplementary Table 1. Secondly, we conducted an intuitive visual inspection to ensure that the simulated curves aligned with the clinical trial. Supplementary Figure 1 presents a graphical representation of the reconstructed distribution curves for each respective group. Ultimately, the log-logistic distribution

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TABLE 1 The parameters input of the model.

Parameters	Input value	Range		Distribution	References
		Minimum	Maximum		
Log-logistic PFS survival model					
Toripalimab group	$\gamma = 1.53; \lambda = 0.033$	-	-	-	(10)
Placebo plus chemotherapy group	$\gamma = 2.01; \lambda = 0.024$	-	-	-	(10)
Log-logistic OS survival model					
Toripalimab group	$\gamma = 1.69; \lambda = 0.0027$	-	-	-	(10)
Placebo plus chemotherapy group	$\gamma = 1.88; \lambda = 0.0030$	-	-	-	(10)
TEAE rate of toripalimab group (%)					
Leukopenia	25.20	-	-	Beta	(10)
Neutropenia	26.30			Beta	(10)
Anemia	4.00	-	-	Beta	(10)
TEAE rate of placebo plus chemotherapy group (%)					
Leukopenia	23.40	-	-	Beta	(10)
Neutropenia	28.60	-	-	Beta	(10)
Anemia	2.90	-	-	Beta	(10)
Drug cost ($)					
Toripalimab (240 mg)	267.36	200.52	334.20	Gamma	(14)
Nab-paclitaxel (100 mg)	105.96	79.47	132.45	Gamma	(14)
Subsequent therapy per cycle ($)	137.61	103.21	172.01	Gamma	(14)
Cost of TEAE per cycle ($)					
Leukopenia	104.95	78.71	131.19	Gamma	(15)
Neutropenia	547.50	410.63	684.38	Gamma	(16)
Anemia	607.06	455.30	758.83	Gamma	(16)
Best supportive care ($)	359.00	269.25	448.75	Gamma	(16)
Follow-up cost per cycle ($)	170.00	127.50	212.50	Gamma	(17)
Utility					
Leukopenia	0.09	0.07	0.11	Beta	(17)
Neutropenia	0.09	0.07	0.11	Beta	(17)
Anemia	0.12	0.09	0.15	Beta	(17)
Progression-free disease	0.76	0.57	0.95	Beta	(18)
Progressive disease	0.55	0.41	0.69	Beta	(18)
Discount rate	0.05	0.00	0.08	Beta	(19)
Body surface area (m^2)	1.72	1.29	2.15	Beta	(16)

was conclusively found to provide the optimal fit for the purpose of simulating survival curves.

In order to improve the effectiveness of our model, a simulation approach was implemented to generate survival times based on the log-logistic distribution. This innovative technique allowed us to extend the potential applicability of our model beyond the duration of the clinical trial follow-up. By providing a robust estimation of the survival function, denoted as S(t), we aimed to offer a more comprehensive understanding of the underlying dynamics of the population under study. In our study, we employed the log-logistic distribution to model the survival function, which can be expressed as $S(t) = 1/(1 + \lambda t^{\gamma})$ (20). This parametric distribution plays a crucial role in survival analysis due to its flexibility in capturing various shapes of survival curves. The estimated values of the parameters, namely shape (γ) and scale (λ), are presented in Table 1.

2.4 Cost and utility

Our model offers a comprehensive framework for evaluating the economic implications of treatment for mTNBC by encompassing a diverse range of significant direct healthcare expenditures. These expenditures include medication costs, management of adverse events, follow-up therapeutic interventions, and optimal supportive care.

In order to obtain precise information regarding drug costs, we obtained national median drug prices from the China Data Platform (https://data.yaozh.com/). These prices were then utilized as inputs for the analysis of drug prices in our study. Additional costs were derived from relevant literature sources that have been previously published. In this study, utility values ranging from 0 to 1 were employed to assess the quality of life associated with health status. However, we were unable to obtain explicit utility value data from the TORCHLIGHT clinical trial. Therefore, we resorted to obtaining utility values from previously published literature. It is important to note that these cost and utility values obtained from the literature are incorporated into our sensitivity analysis, which aims to assess the robustness of our model's results by examining their impact on the conclusions drawn from our findings. Furthermore, our model also considers the negative utility associated with adverse drug events. Table 1 provides comprehensive information on the cost and utility values.

2.5 Sensitivity analysis

This study employed sensitivity analysis to bolster the robustness of the model. A one-way sensitivity analysis was performed, wherein each input parameter was altered by ±25% to evaluate the influence of these parameters on the ICER. Furthermore, the discount rate was varied from 0 to 8%. The findings of this sensitivity analysis were graphically presented using tornado diagrams.

In order to rigorously evaluate the uncertainty surrounding the estimation of ICERs in this study, a Probabilistic Sensitivity Analysis (PSA) was also performed. A total of 1,000 Monte Carlo simulations were conducted in this analysis. The primary objective of the PSA was to randomly sample input parameters from specific probability distributions. This approach enables a comprehensive and robust assessment of the potential variability in the estimated ICERs, while considering the inherent uncertainty associated with each parameter. By drawing samples from designated probability distributions, the PSA not only considers deterministic parameter values but also incorporates probabilistic elements. The results of the probabilistic sensitivity analysis are visually presented through scatter plots.

3 Results

3.1 Base case cost-effectiveness results

The study's findings revealed that the total expenditure for the group receiving toripalimab was $38,040.62, while the placebo plus chemotherapy group incurred a total cost of $26,102.07.

TABLE 2 The results of cost-effectiveness.

Base case	Toripalimab plus chemotherapy group	Placebo plus chemotherapy group
Cost ($)	38,040.62	26,102.07
QALYs	2.47	1.73
Incremental cost ($)	11,938.55	NA
Incremental QALY	0.74	NA
ICER ($/QALY)	16,133.18	NA

Additionally, the toripalimab regimen led to an increase of 0.74 QALYs compared to the placebo plus chemotherapy group. However, it should be noted that this additional benefit came with an incremental cost of $11,938.55. Consequently, the ICER was calculated to be $16,133.18 per QALY gained. Importantly, this ICER value is lower than the WTP threshold of $39,855.79 per QALY in China, suggesting that the use of the toripalimab regimen can be considered cost-effective within the Chinese healthcare system. Table 2 presents a summary of the findings gleaned from this analysis.

3.2 Sensitivity analysis on the cost-effectiveness results

Figure 2 presents a tornado diagram that showcases the results of a one-way sensitivity analysis. The most prominent factor affecting the ICER was found to be the cost of the best supportive care. However, it is worth noting that this impact fluctuated within a range of ±25%, which remains significantly lower than the designated threshold of WTP. Importantly, such fluctuations did not overturn the study's findings. Furthermore, other parameters such as PD utility, PFS utility, and subsequent therapy costs played a role in influencing the ICER; however, their impact gradually diminished. It is crucial to underscore that altering these parameters within a range of ±25% did not lead to substantial changes in the analysis results. Consequently, the persistent finding that the ICER value consistently remains below three times the GDP strengthens the stability and reliability of our findings.

In Figure 3, the ICER plane provides a comprehensive illustration of the dispersion of the 1,000 bootstrap replicates of the ICER. This graphical representation provides valuable insights into the cost-effectiveness of different interventions. Based on the findings obtained from the analysis, interventions falling below the linear ICER line are considered to be cost-effective. This positioning implies that interventions in this quadrant exhibit a more favorable ICER ratio, indicating lower costs or greater effectiveness compared to interventions in other quadrants. Notably, considering the WTP threshold of $39,855.79 per QALY, there is a 99.60% probability of classifying the toripalimab regimen as a more cost-effective option in comparison to the placebo plus chemotherapy group.

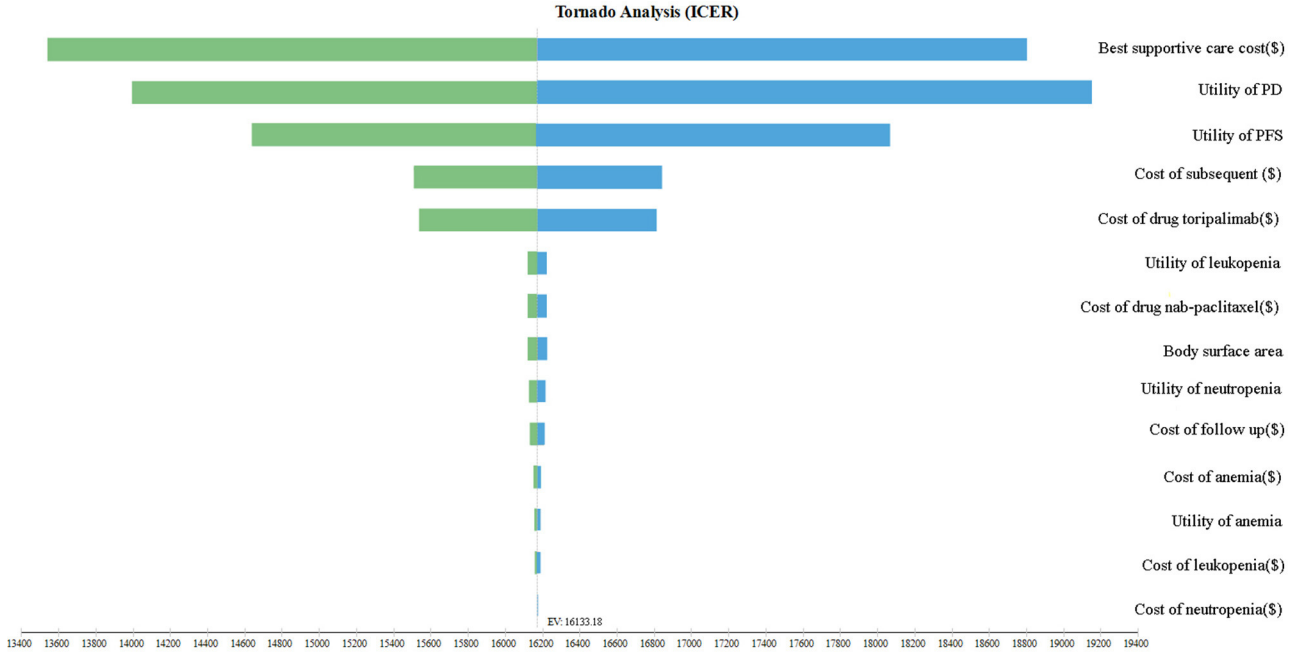


FIGURE 2
The tornado diagram.

4 Discussion

In recent years, China has achieved notable advancements in the field of cancer treatment, particularly in the development of innovative PD-1 or PD-L1 inhibitors (21). These inhibitors have demonstrated remarkable efficacy in enhancing the survival rates and clinical tolerance of individuals affected by various forms of cancer, significantly augmenting the prospects of cancer treatment (22). The centralized price negotiation mechanism has played a pivotal role in facilitating this positive trend, aiming to enhance the accessibility and affordability of these therapeutic interventions for patients (23). Furthermore, the implementation of a prioritized approval process in China has expedited the development, review, and approval of novel drugs. These initiatives have not only accelerated the introduction of innovative therapeutic agents but have also enabled timely access to treatment for patients in dire need (24). Consequently, these advancements in cancer treatment have not only positively impacted the lives of cancer patients in China but have also garnered global attention.

Toripalimab is a selective, recombinant, humanized monoclonal antibody against PD-1 (25). The TORCHLIGHT study aimed to compare the efficacy of toripalimab plus nab-paclitaxel vs. placebo plus chemotherapy as a first-line treatment for mTNBC. The study demonstrated that the mPFS was significantly improved by 2.8 months in the experimental arm, and there was a notable 35% reduction in the risk of disease progression or death. Moreover, a descriptive analysis of OS indicated a favorable trend in both the PD-L1-positive and ITT populations. These findings provide further validation for the clinical utility of incorporating PD-1 checkpoint blockade alongside chemotherapy to treat mTNBC. Our research conducted a rigorous and comprehensive cost-effectiveness analysis utilizing the ICER as a valuation metric to assess the affordability and value of toripalimab for the treatment of mTNBC.

To assess the cost-effectiveness of toripalimab, we employed a partitioned survival model to simulate the progression of disease and treatment outcomes over a 10 years time horizon. The model incorporated data from clinical trials and published literatures to estimate the outcomes and costs associated with toripalimab treatment. Our findings demonstrated that toripalimab was associated with a higher efficacy, indicated by improved the QALY, compared to the placebo plus chemotherapy treatment options. The combination therapy of toripalimab in conjunction with nab-paclitaxel has demonstrated a highly favorable ICER of $16,133.18 per QALY gained for the management of mTNBC. This ICER value is significantly lower than the WTP threshold of $39,855.79 per QALY. As a result, it suggests that incorporating the use of toripalimab plus nab-paclitaxel as a first-line treatment option for mTNBC in China has the potential to be deemed a cost-effective approach.

Our study also conducted sensitivity analyses to investigate the potential influence of changes in input variables on the outcomes of the study and model. By delving into the sensitivities of various parameters, we aimed to gain a deeper understanding of the interdependencies and the response of study results to individual factors. Notably, we identified several key factors that had a significant impact on the ICER, including the cost of the best supportive care, utility values for PFS and PD, and subsequent therapy costs. Importantly, we consistently observed that the resulting ICERs remained below the WTP thresholds, even when we varied all input parameters within a range of ±25%. This finding indicates that

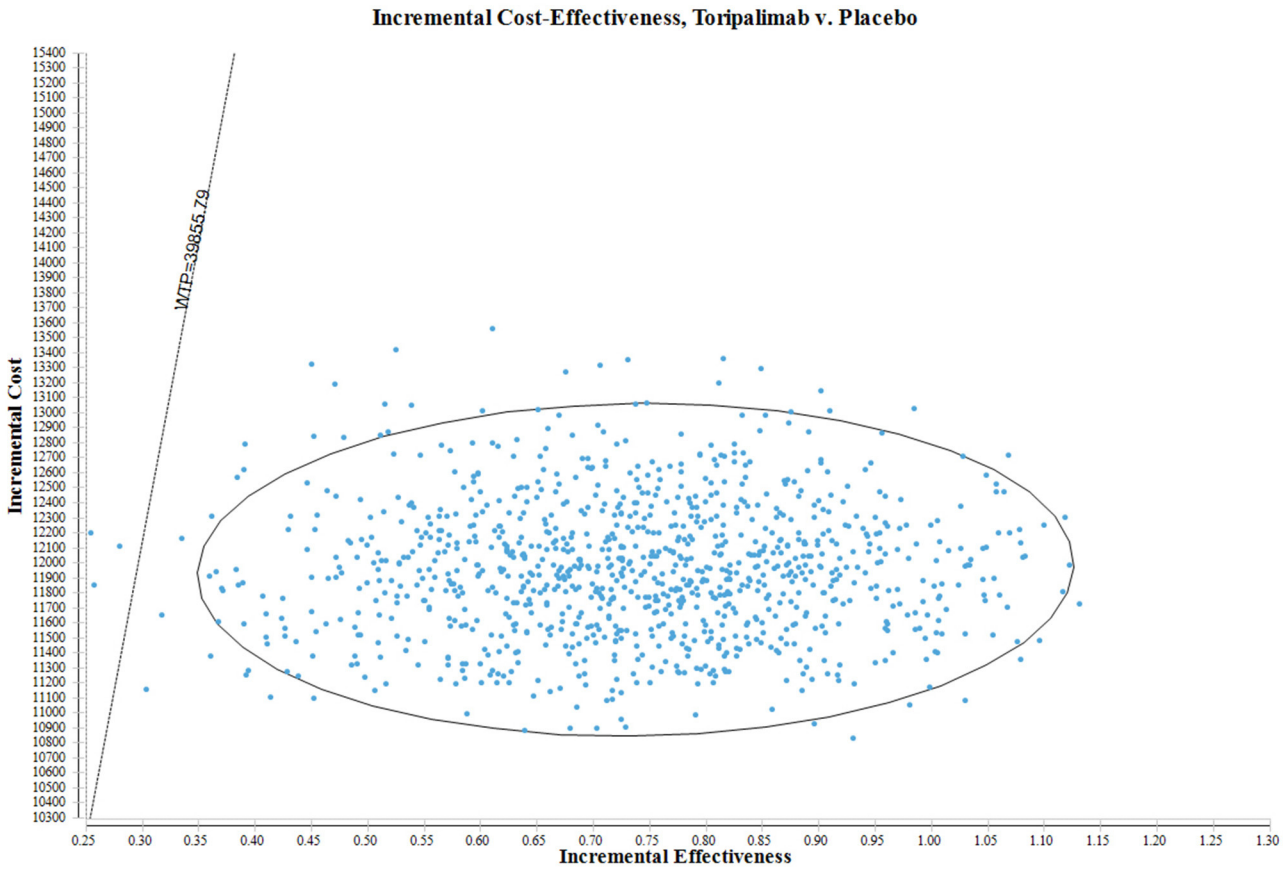


FIGURE 3
The scatter plot of PSA.

the use of toripalimab for mTNBC is a cost-effective strategy in China.

Currently, there are some research efforts are being dedicated to conducting economic evaluations of immunotherapies for patients with mTNBC. For example, a study by Liu et al. used a cost-effectiveness analysis to compare adding atezolizumab to paclitaxel for advanced or metastatic TNBC. The findings of this study indicated that adding atezolizumab to nab-paclitaxel is not a cost-effective strategy compared to nab-paclitaxel monotherapy for Chinese patients with advanced or metastatic TNBC in China (26). Another study by Lang et al. focused on evaluating sacituzumab govitecan compared with standard of care chemotherapy from the United States payer perspective. Their results demonstrated that sacituzumab govitecan at current price is unlikely to be a preferred option for patients with advanced or metastatic TNBC at a threshold of $ 150,000/QALY (27).

Cost-effectiveness analyses are essential tools for evaluating the value of therapies in healthcare (28). These analyses involve comparing the costs and outcomes of various treatment options, allowing healthcare professionals and policymakers to make informed decisions based on the available evidence. One crucial aspect that cost-effectiveness analyses assess is the impact of the therapy on health outcomes. Improved health outcomes are the ultimate objective of any treatment (29). Our study has concluded that the cost-effectiveness analyses demonstrate favorable ICER. This indicates that the utilization of toripalimab can substantially enhance health outcomes at a justifiable cost. This finding provides strong support for advocating the inclusion of toripalimab in treatment guidelines for mTNBC and for shaping healthcare reimbursement policies. By integrating toripalimab into treatment guidelines, healthcare providers can ensure that patients have access to a therapy that has proven to be both effective and cost-effective.

The correlation between the cost per QALY and a country's GDP per capita is a pivotal factor in determining cost-effectiveness thresholds. This association defines the threshold point at which the acquisition cost of a QALY becomes a determining factor in evaluating the value and feasibility of a certain intervention or policy decision within a given healthcare system (30). The concept of WTP per QALY encapsulates the notion that individuals are willing to assign a specific monetary value to acquire an additional year of life in perfect health or experience substantial enhancements in their quality of life (31). By quantifying this willingness to pay, policymakers and healthcare decision-makers gain a deeper insight into the relative value of various healthcare interventions and can apportion limited resources in a prudent manner. In this study, we have employed a threshold for the WTP criterion, which is set at 3 times the GDP, equivalent to $39,855.79 per QALY.

This threshold aligns with the guidelines provided by the Chinese Pharmacoeconomics Guidelines. The ICER for toripalimab, when compared to placebo plus chemotherapy, was estimated to be $16,133.18 per QALY gained. Importantly, the ICER value we obtained is considerably lower than the generally accepted WTP threshold of $39,855.79 per QALY. This result suggests that the utilization of toripalimab as a first-line treatment for mTNBC has the potential to be considered economically efficient. Furthermore, even in the current context where some researchers and scholars propose reducing the WTP threshold to 1.5 times the GDP (32), our study demonstrates that the use of toripalimab for mTNBC would still be cost-effective in China.

It is crucial to acknowledge the limitations inherent in our study. Firstly, it should be noted that the data we have utilized for this cost-effectiveness analysis primarily originates from clinical trials. Nonetheless, it is imperative to acknowledge the necessity of ongoing monitoring and updating of these findings. As new evidence emerges and the landscape of cost and efficacy evolves, it becomes vital to continuously reassess and revise our conclusions. Secondly, it is crucial to acknowledge the assumption made in this study regarding the cost of the best supportive care and second-line treatments after disease progression. However, it is worth considering that in real word situations, the selection of best supportive care and subsequent treatment options would vary depending on the unique circumstances of each patient. Fortunately, the one-way sensitivity analyses conducted in this study provide reassurance as they consistently demonstrate that even when the estimated ranges for the cost of best supportive care and subsequent treatments are adjusted, the ICER values remain below the WTP threshold. Finally, we exclude grade 1 or 2 adverse events from our analysis due to the assumption that these events have negligible effects on both clinical outcomes and costs. Moreover, our sensitivity analyses confirm the robustness of our findings, as our results remain consistent even when accounting for variations within a range of 25% for grade 3 or higher adverse events. Despite the aforementioned limitations, the study findings remain robust due to the sensitivity analyses conducted. The consistent findings across different sensitivity analyses, where the ICER values remained below the WTP threshold, provide confidence in the cost-effectiveness of the intervention. This demonstrates that even in scenarios where the cost assumptions are modified, the overall conclusion regarding the cost-effectiveness of the intervention remains unchanged.

5 Conclusion

Our findings suggest that toripalimab plus chemotherapy in the management of mTNBC is cost-effective compared to placebo plus chemotherapy with an ICER below the WTP threshold in China. These results provide valuable insights for policymakers and healthcare providers in decision-making regarding the optimal treatment strategy for mTNBC patients.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

ZZ: Validation, Writing – original draft, Writing – review & editing. LH: Data curation, Investigation, Software, Writing – original draft. HC: Project administration, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1421826/full#supplementary-material

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Point-of-care Testing HbA1c screening for type 2 diabetes in urban and rural areas of China: a cost-effectiveness analysis

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Background: Point-of-care Testing (POCT) glycosylated hemoglobin (HbA1c) is a convenient, cheap, effective and accessible screening method for type 2 diabetes in rural areas and community settings that is widely used in the European region and Japan, but not yet widespread in China. The study is the first to evaluate the cost-effectiveness of POCT HbA1c, fasting capillary glucose (FCG), and venous blood HbA1c to screen for type 2 diabetes in urban and rural areas of China, and to identify the best socio-economically beneficial screening strategy.

Methods: Based on urban and rural areas in China, economic models for type 2 diabetes screening were constructed from a social perspective. The subjects of this study were adults aged 18–80 years with undiagnosed type 2 diabetes. Three screening strategies were established for venous blood HbA1c, FCG and POCT HbA1c, and cost-effectiveness analysis was performed by Markov models. One-way sensitivity analysis and probabilistic sensitivity analysis were performed on all parameters of the model to verify the stability of the results.

Results: Compared with FCG, POCT HbA1c was cost-effective with an incremental cost-utility ratio (ICUR) of $500.06/quality-adjusted life year (QALY) in urban areas and an ICUR of $185.10/QALY in rural areas, within the willingness-to-pay threshold (WTP = $37,653). POCT HbA1c was cost-effective with lower cost and higher utility compared with venous blood HbA1c in both urban and rural areas. In the comparison of venous blood HbA1c and FCG, venous blood HbA1c was cost-effective (ICUR = $20,833/QALY) in urban areas but not in rural areas (ICUR = $41,858/QALY). Sensitivity analyses showed that the results of the study were stable and credible.

Conclusions: POCT HbA1c was cost-effective for type 2 diabetes screening in both urban and rural areas of China, which could be considered for future clinical practice in China. Factors such as geographic location, local financial situation and resident compliance needed to be considered when making the choice of venous blood HbA1c or FCG.

KEYWORDS

type 2 diabetes, Point-of-care Testing, glycated hemoglobin assay, capillary glucose, cost-effectiveness analysis, Markov model

1 Introduction

Type 2 diabetes poses one of the biggest public health problems affecting hundreds of millions of people worldwide, with significant morbidity and mortality implications for individual patients and families as well as considerable economic impact on national health care systems (1). Type 2 diabetes is associated with both macrovascular and microvascular complications, which greatly increase both the disability and mortality rates. It is estimated that about 6 million people with type 2 diabetes in China suffer from more than one complication (2). Among urban Chinese residents, 73–81% of direct diabetes-related medical costs are spent on the treatment of diabetic complications (3).

A meta-analysis showed an increased risk of all-cause mortality and cardiovascular mortality in patients with type 2 diabetes associated with blood glucose levels (4). The United kingdom Prospective Diabetes Study results showed that a mean glycosylated hemoglobin (HbA1c) of 53 mmol/mol (7.0%) reduced the risk of diabetes-related endpoints by 12–32% compared to a mean HbA1c of 63 mmol/mol (7.9%) (5). The prevalence and mortality of type 2 diabetes in rural areas of China are increasing yearly (6, 7). However, the frequency of self-monitoring of blood glucose in Chinese rural residents is relatively low, and the glycemic target attainment rate is <19% (8). A study from Taiwan (9) reported that patients with type 2 diabetes in rural areas had a higher risk of developing chronic complications than those in urban areas. These studies all demonstrate the urgency of early diagnosis of type 2 diabetes and the importance of early glycemic target attainment to prevent further complications.

The oral glucose tolerance test (OGTT) is the gold standard for diagnosing type 2 diabetes. HbA1c is a commonly used indicator for monitoring glycemic control in clinical practice, as well as one of the diagnostic criteria for diabetes (10). However, the strict quality control requirements for venous HbA1c render it unavailable in many remote areas of rural China. Fingertip fasting capillary glucose (FCG) is the most common method for initial screening of diabetes and self-monitoring of blood glucose in the daily life of Chinese residents. However, FCG is affected by short term lifestyle changes, as well as environmental humidity and temperature, with poor repeatability and stability, and the sensitivity of screening for type 2 diabetes in the Chinese population is only 65.1% (11). Point-of-care Testing (POCT) glycosylated hemoglobin (HbA1c) is a minimally invasive HbA1c test that provides rapid results by collecting the subject's fingertip blood and analyzing it immediately at the sampling site. Importantly, POCT HbA1c analyzers are currently used in about 75% of European healthcare facilities (12). In Japan, a community-based specimen measurement office was initiated and offered POCT HbA1c testing in 2014, and a cost-effectiveness analysis in 2018 showed that POCT HbA1c was more effective and less costly compared with the status quo (HbA1c testing that was available only during Specific Health Checkup visits and conventional opportunistic screening in clinics) (13). Studies in recent years have shown that most POCT HbA1c measurement instruments can satisfy the quality specifications with high accuracy and sensitivity (12, 14, 15). Nevertheless, in China, POCT HbA1c testing is not yet widely used in clinical practice and relatively few clinical studies have been conducted. There are no cost-effectiveness studies of POCT HbA1c in China.

In this study, a cost-effectiveness analysis of three screening strategies for type 2 diabetes (POCT HbA1c, venous blood HbA1c and FCG) was conducted in rural and urban areas from a social perspective to identify the most economically efficient screening method. This is the first cost-effectiveness study of POCT HbA1c in China, which could provide a foundation and reference for the application of POCT HbA1c in type 2 diabetes screening in urban and rural areas of China.

2 Methods

2.1 Study design

This study presented a social perspective to construct diabetes screening strategies based on venous HbA1c, FCG, and POCT HbA1c by decision tree model, and performed cost-effectiveness analysis of the three screening methods by Markov model to determine the economically efficient strategy in urban and rural areas of China, respectively. Treeage Pro 2022 software was used for model construction and computation. We searched the databases of China National Knowledge Infrastructure, PubMed, and Web of Science, selected representative large retrospective studies, cohort studies, and relevant cost-effectiveness analysis studies from 2012 to 2022, and referred to annual government statistical reports, local government reports and price lists to obtain the parameters required for decision tree model and Markov models.

The major literature inclusion criteria were as follows: (1) Subjects: Adults (≥18 years old) without a diagnosis of type 2 diabetes, Chinese population was preferred, if there was no relevant study in the Chinese population, Asian population (e.g., Japan) was preferred, followed by European population. (2) Study types: (1) Transition probabilities: large cohort studies or cost-effectiveness analysis studies, of which cohort studies had a follow-up period of not <3 years; (2) Costs: large cross-sectional studies, retrospective studies, or cost-effectiveness analysis studies in Chinese regions; (3) Utilities: cost-effectiveness analysis studies (preferred in Chinese regions). (3) Literature publication period: 2012–2022. Exclusion criteria included: (1) Study participants were children, adolescents, or pregnant women, with a previous diagnosis of pre-diabetes or type 1 diabetes or a specific type of diabetes. (2) Studies not formally published, such as conference abstracts. (3) Written and published in languages other than Chinese and English.

The Markov chain Monte Carlo simulation method was used to estimate the disease process of 10 million adults (18 years and older) with no previous diagnosis of type 2 diabetes (exclusion of prediabetes, type 1 diabetes, or specific types of diabetes). The age and the male-to-female sex ratio of the baseline population was calculated based on the China Statistical Yearbook 2021 (16) (Supplementary Table 1). In this study, we used 1 year as a circulation period, and the model termination condition is age ≥80 years. Due to the long and continuous disease course of type 2 diabetes, the discretization process of the Markov model may produce some error, so the model was corrected by half-cycle correction. In addition, this study made assumptions about the model: (1) all type 2 diabetes patients were in a stable baseline state (without complications) before entering the long-term Markov

model. (2) Transitions between states in the Markov model of the subject do not affect the next cycle of transitions (17).

2.2 Model construction and setup

This study included decision tree models for three screening strategies and Markov models for simulating disease progression.

The decision model in this study simulated the process of screening for type 2 diabetes in the population using POCT HbA1c, FCG, and venous blood HbA1c (as shown in Figure 1). Following the screening test, positive individuals would be further tested with an OGTT. If OGTT is positive, type 2 diabetes would be diagnosed and treatment would be initiated [enter the Markov (+) model], and if OGTT is negative, misdiagnosis would be considered [enter the Markov (-) model]. Those who screen negative would not be further examined and treated [Markov (-) model], but if the subject are patients with type 2 diabetes, they are considered to be missed [Markov (+) model]. The sensitivity and specificity of the different screening methods determine the rate of missed and misdiagnosis of screening, and influence the disease progression process of the subject.

Markov (+) model (Figure 2A): including type 2 diabetes without complications, type 2 diabetes with various related complications and death. The complications included macrovascular complications (cardiovascular disease, stroke) and microvascular complications (diabetic kidney disease, diabetic foot ulcers, diabetic retinopathy, and diabetic peripheral neuropathy). In particular, diabetic kidney disease, diabetic foot ulcers and diabetic retinopathy could progress to end-stage renal disease, amputation and blindness. Type 2 diabetes with or without complications may cause multiple complications or death. In the process, different complications affected the health status of patients with type 2 diabetes in different ways, resulting in corresponding costs.

Markov (-) model (Figure 2B): including non-type 2 diabetes and death. Subjects in this model may continue to maintain the non-type 2 diabetes state or death.

2.3 Costs

All costs of the three screening methods for type 2 diabetes were collected from the social perspective, including direct medical costs, direct non-medical costs and indirect costs. The direct medical costs were the medical resources consumed by the disease, such as registration fees, test fees and medical staff time costs. Registration and testing fees were referenced to local health service prices, and medical staff time costs are obtained from the average salary of medical staff published by the National Bureau of Statistics of China in 2021 (19). Direct non-medical costs were costs incurred in seeking and waiting for test results (e.g., transportation, accommodation, etc.). The direct non-medical costs in urban areas were obtained from a cost-effectiveness study in Chinese communities (20), and direct non-medical costs in rural areas were obtained from a cross-sectional study in rural southwest China (21). Indirect costs were costs incurred by subjects for time spent on medical visits and waiting, calculated as the average hourly wage of the Chinese population (22). The detailed cost components and model input parameters were shown in the Supplementary Table 2 and Supplementary Table 3A.

After the development of complications in type 2 diabetes, it is difficult to calculate the direct non-medical costs and indirect costs resulting from different types of complications due to the large differences in disease duration, treatment options and prognosis, so only the direct medical costs of type 2 diabetes complications were included in this study as approximate total costs. Costs of complications were derived from previously published cross-sectional studies based on Chinese populations, retrospective studies, and relevant cost-effectiveness studies (as shown in Supplementary Table 3B). All costs were converted to US dollars at an exchange rate of US$1.0 = CNY6.4 (2022). Because the study period was >1 year and there may be socioeconomic inflation, this study discounted the future costs and health outputs from the screening measures (the discount rate was taken as 5%). A sensitivity analysis was also performed for discount rates between 0 and 8%.

2.4 Utilities

The utility values for this study were set to quality-adjusted life years (QALYs). The utility values were derived from cost-effectiveness studies based on Chinese populations, except for the utility values for diabetic neuropathy and multiple complications, which were referenced from cost-utility analysis studies in European regions. The specific parameter values were shown in Supplementary Table 4.

2.5 Transition probabilities

The prevalence of type 2 diabetes in urban and rural areas in this study was derived from a Chinese cross-sectional study in 2020 (23). The sensitivity and specificity of the three screening strategies were derived from diagnostic studies based on Chinese populations (11, 15, 18). The transition probabilities of various complications were mainly derived from cohort studies and cost effectiveness analyses based on Chinese populations, some of which were referred to foreign studies because no relevant studies were available in China. In addition, a 10-year cohort study showed that in patients with HbA1c of 7–8%, the risk ratio (HR) for microvascular complications was 1.391, HR for macrovascular complications was 1.287, and HR for death was 1.290 (24). Therefore, in this study, for patients with missed diagnosis type 2 diabetes, the transition probabilities of complications were set as the original transition probabilities multiplied by the corresponding HR.

In terms of urban-rural differences, a study in Taiwan, China, showed that the risk of cardiovascular events in type 2 diabetes was 1.15 times higher in rural areas than in urban areas, and the HRs for stroke, blindness, lower limb ulcers, and end-stage renal disease were 1.25, 2.09, 1.42, and 1.15, respectively (9). Therefore, in this study, the

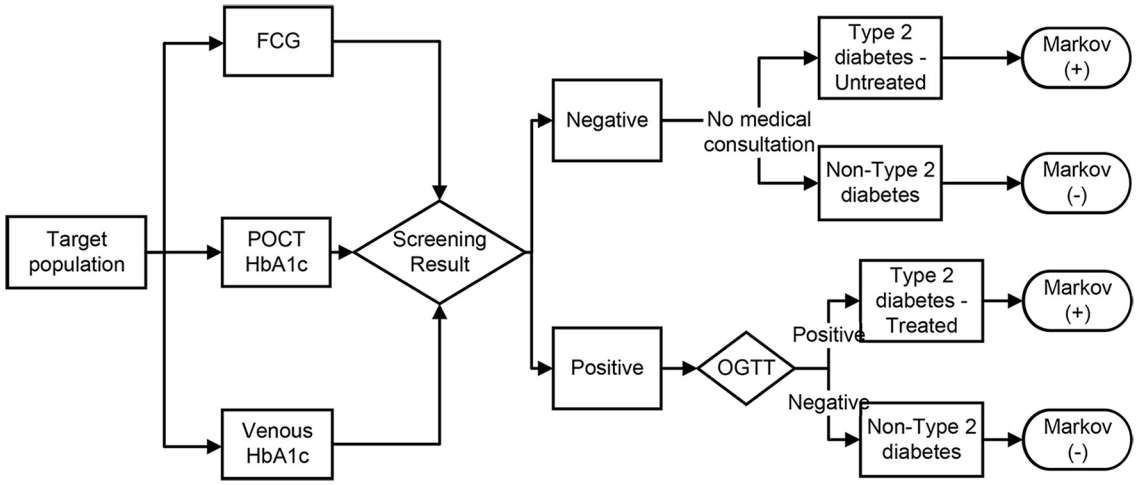


FIGURE 1
Decision model for the three screening strategies. FCG, fasting capillary blood glucose; POCT, point-of-care test; OGTT, oral glucose tolerance test. Screening positive: POCT HbA1c test value ≥43.6 mmol/mol (6.14%) (15), venous blood HbA1c test value ≥44.8 mmol/mol (6.25%) (18), FCG test value ≥6.1 mmol/L (11), OGTT test with fasting plasma glucose ≥7.0 mmol/L and/or 2 h plasma glucose after oral 75 g of glucose powder ≥11.1 mmol/L (10).

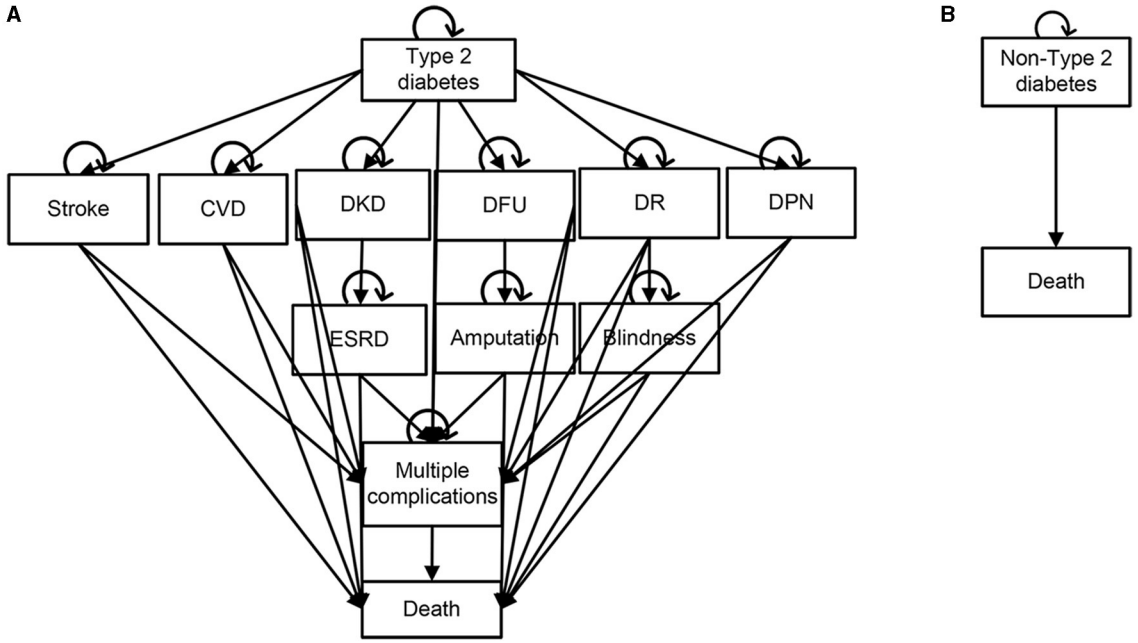


FIGURE 2
Schematic diagrams of Markov model. **(A)** Type 2 diabetes [Markov(+)] model. **(B)** Non-type 2 diabetes [Markov(-)] model. CVD, Cardiovascular Disease; ESRD, End-Stage Renal Disease; DKD, Diabetic kidney disease; DFU, Diabetic foot ulcer; DR, Diabetic retinopathy; DPN, Diabetic peripheral neuropathy.

transition probabilities of complications in rural areas were set as the original transition probabilities multiplied by the corresponding HR.

The specific transition probability parameter values and references were detailed in Supplementary Table 5. All transition probabilities were subjected to sensitivity analysis.

2.6 Evaluation methods

This study conducted a cost-effectiveness analysis and used the incremental cost-utility ratio (ICUR) as an outcome indicator to explain the results of the cost-effectiveness analysis. The ICUR was the cost per additional QALY for the subject, which was compared to the willingness-to-pay threshold (WTP) to assess the economic

advantages of different screening strategies. The WTP is usually 1–3 times the gross domestic product (GDP) per capita. The GDP per capita in China in 2021 is ~$12,551 (25), and the WTP of this study was taken as 3 times the GDP per capita ($37,653).

2.7 Sensitivity analysis

To evaluate the extent to which factors such as model building, parameter differences and evaluation methods affected the study results during the study, we performed one-way sensitivity analysis and probabilistic sensitivity analysis on all input model parameters (including costs, prevalence of type 2 diabetes, screening effectiveness, transition probabilities, utilities, and discount rate) to verify whether the study results were stable and reliable. In the one-way sensitivity analysis, the ranges of different parameters were varied using the 95% confidence intervals given in the references, and if only the mean value of the parameter was reported in the data source, the base data ± 20% was used as the range of variation of the parameter for the sensitivity analysis. The probabilistic sensitivity analysis was designed to assess the combined effect of multiple parameter changes on the model results. All parameters were set to probability distributions for 1,000 iterations.

(1) For dichotomous variables, if the number of occurrences and the sample size were reported in the previous literature, a beta distribution is appropriate and the probability density function is as follows. Where α represents the number of events that occurred and β represents the number of events that did not occur. The parameters for fitting the beta distribution in this study are shown in Supplementary Table 6A.

$$f_{(x;\alpha;\beta)} = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\,\Gamma(\beta)} x^{\alpha-1}(1-x)^{\beta-1}$$

(2) Health costs or prices are usually distributed as skewed. This study assumes that both screening and complication costs follow a lognormal distribution, taking the log mean as the median and the standard deviation as 10% of the mean. The probability density function is as follows (μ denotes the log mean and σ denotes the log standard deviation). The parameters for fitting the lognormal distribution in this study are shown in Supplementary Table 6B.

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{\left(\frac{-(\ln(x)-\mu)^2}{2\sigma^2}\right)}$$

(3) All other variables were fit to a uniform distribution as the parameters of the particular distribution could not be derived from previous literature or from the actual situation. The parameters for the uniform distribution utilized in this study are presented in Supplementary Table 6C.

3 Results

3.1 Cost-effectiveness analysis results

The cost-effectiveness analysis results were shown in Table 1.

In urban areas, the lifetime costs per capita for FCG, POCT HbA1c, and venous blood HbA1c were $1,911.10, $1,956.44, and $2,536.09, respectively. In terms of utility, POCT HbA1c had the highest QALY (QALY = 27.21), which was 0.09 and 0.06 higher than FCG (QALY = 27.12) and venous blood HbA1c (QALY = 27.15), respectively. Compared with FCG, the ICUR for POCT HbA1c was $500.06/QALY, which was within the WTP ($37,653) threshold. Compared with venous blood HbA1c, POCT HbA1c had lower cost and higher utility with cost-effectiveness. Venous blood HbA1c was cost-effective with an ICUR of $20,833/QALY compared to FCG, within the WTP threshold.

In rural areas, the lifetime costs per capita for FCG, POCT HbA1c, and venous blood HbA1c were $2,051.15, $2,062.00, and $2,888.31, respectively. In terms of utility, POCT HbA1c had the highest QALY (QALY = 26.60), which was 0.06 and 0.04 higher than FCG (QALY = 26.54) and venous blood HbA1c (QALY = 26.56), respectively. Compared with FCG, the ICUR of POCT HbA1c was $185.10/QALY, which was within the WTP ($37,653) threshold. Compared with venous blood HbA1c, POCT HbA1c had lower cost and higher utility with cost-effectiveness. Venous blood HbA1c had an ICUR of $41,858/QALY compared to FCG, which is greater than the WTP threshold.

The cost-utility acceptability curve of the three screening strategies in both urban and rural areas were shown in Figure 3. The probability that POCT HbA1c was cost-effective was 100% for each when the WTP = $37,653.

3.2 Sensitivity analysis results

Due to the large number of input parameters to the models, this study presented the results of the one-way sensitivity analyses of all the parameters together through the tornado diagrams of ICUR values (Supplementary Figure 1). In the tornado diagrams, a horizontal band was generated for each analyzed variable, the length of which represented the magnitude of its impact on the model results, and all parameters were ordered from top to bottom according to the magnitude of their impact on the models. The vertical lines in the figure represented the mean ICUR values obtained from the model operations. In comparison of POCT HbA1c with FCG and venous blood HbA1c, the ICUR values for each parameter did not exceed the WTP of this study when the parameters were varied within their sensitivity analysis in both urban and rural areas, and the results of the study were relatively stable. In comparison of venous blood HbA1c with FCG, the ICUR value for each parameter did not exceed the WTP in urban areas, while in rural areas, the factors that had a greater impact on the results were the discount rate, prevalence of type 2 diabetes in rural areas, transition probability of multiple complications, etc. the ICUR value exceeded the WTP, which had an impact on the study results considering the variation of the above parameters within the reference range.

TABLE 1 Results of cost-effectiveness analysis of three screening strategies.

	Cost ($)	Incremental cost ($)	Utility (QALY)*	Incremental utility (QALY)	C/U	ICUR ($/QALY)
Urban area						
FCG	1,911.10	-	27.12	-	70.46	-
POCT HbA_{1c}	1,956.44	45.33	27.21	0.09	71.90	500.06
Venous blood HbA_{1c}†	2,536.09	579.65	27.15	−0.06	93.41	−10,028.50
Venous blood HbA_{1c}‡	2,536.09	624.99	27.15	0.03	93.41	20,833
Rural area						
FCG	2,051.15	-	26.54	-	77.29	-
POCT HbA_{1c}	2,062.00	10.85	26.60	0.06	77.52	185.10
Venous blood HbA_{1c}†	2,888.31	826.31	26.56	−0.04	108.75	−22,105.23
Venous blood HbA_{1c}‡	2,888.31	837.16	26.56	0.02	108.75	41,858

*Utility: Quality-adjusted life year (QALY).
†Venous blood HbA_{1c} compared with POCT HbA_{1c}.
‡Venous blood HbA_{1c} compared with FCG.
ICUR, incremental cost-utility ratio; HbA_{1c}, glycated hemoglobin; FCG, fasting capillary blood glucose; POCT, point-of-care test.

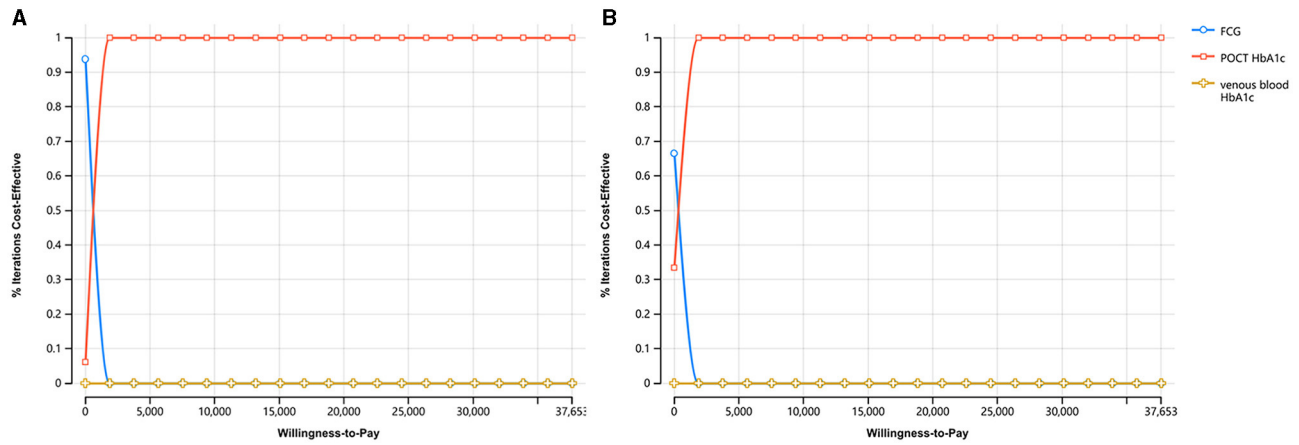


FIGURE 3
The cost-utility acceptability curve of the three screening strategies. **(A)** The cost-utility acceptability curve in urban areas. **(B)** The cost-utility acceptability curve in rural areas.

The scatter plots of ICUR for the three screening strategies in the probabilistic sensitivity analysis were shown in Figure 4. When WTP = $37,653, in urban areas, the probability that POCT HbA1c was cost-effective was 99.9% compared to FCG and 100% compared to venous blood HbA1c. The probability that venous blood HbA1c was cost-effective compared to FCG was 30%. In rural areas, the probability that POCT HbA1c was cost-effective was 99.6% compared to FCG and 100% compared to venous blood HbA1c. The probability that venous blood HbA1c was cost-effective compared with FCG was 9.1%.

4 Discussion

4.1 Analysis of the economic evaluation

In cost-effectiveness analysis, compared with FCG, the ICUR values of POCT HbA1c were within the WTP ($37,653) threshold in urban and rural models, and POCT HbA1c had lower cost and higher utility compared with venous blood HbA1c, suggesting that POCT HbA1c was cost-effective among the three screening strategies in both urban and rural areas of China. While the screening cost of POCT HbA1c was higher than that of FCG, its higher sensitivity in screening reduced the rate of missed diagnosis of type 2 diabetes, which further reduced the incidence and costs of type 2 diabetes-related complications. Compared with venous blood HbA1c, POCT HbA1c had lower cost and higher utility values in both urban and rural areas, which was related to the lower screening cost and higher screening sensitivity of POCT HbA1c.

In the comparison in venous blood HbA1c and FCG, the ICUR of venous blood HbA1c was $20,833/QALY (within the WTP threshold) in urban areas, while the ICUR was $41,858/QALY (greater than the WTP threshold) in rural areas. Venous blood HbA1c was superior to FCG in terms of sensitivity and specificity in screening for type 2 diabetes resulting in higher utility values.

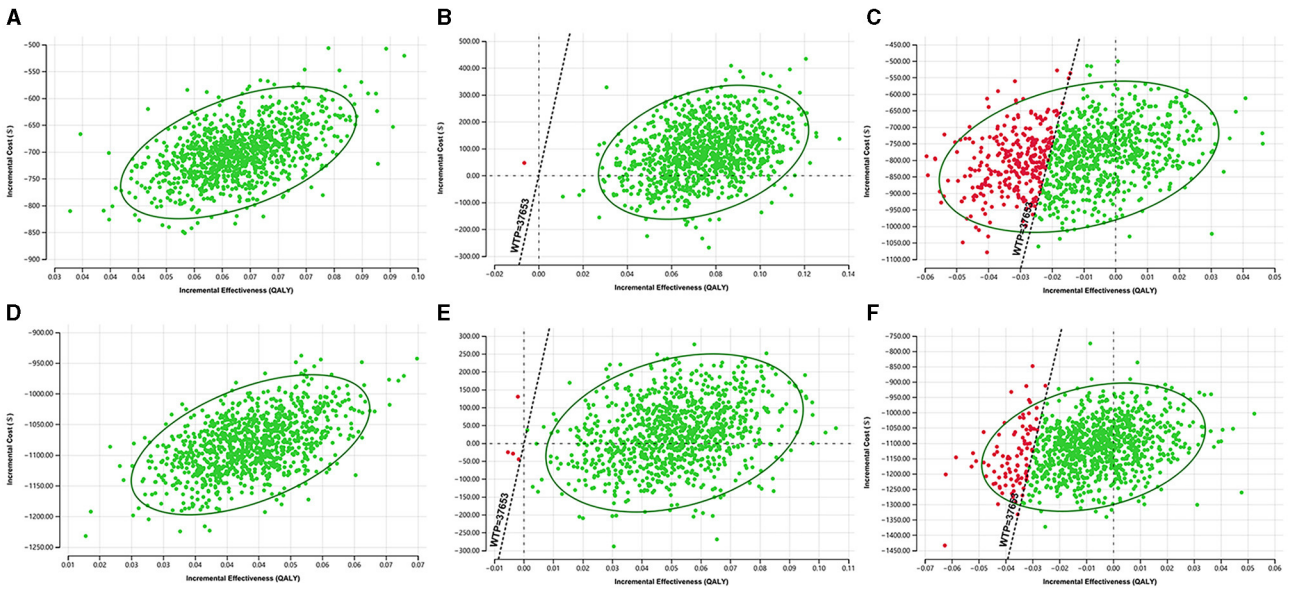


FIGURE 4
The probabilistic sensitivity analysis results of the ICUR in three screening strategies. **(A)** POCT HbA1c vs. FCG in urban areas. **(B)** POCT HbA1c vs. venous blood HbA1c in urban areas. **(C)** Venous blood HbA1c vs. FCG in urban areas. **(D)** POCT HbA1c vs. FCG in rural areas. **(E)** POCT HbA1c vs. venous blood HbA1c in rural areas. **(F)** Venous blood HbA1c vs. FCG in rural areas.

However, the cost of screening for venous blood HbA1c was high as well as the direct non-medical and indirect costs such as transportation, lost wages, and other costs associated with screening for venous blood HbA1c in rural areas. The results indicated that venous blood HbA1c was cost-effective in urban areas whereas FCG was more optimal in rural areas.

There are important urban-rural disparities when considering medical costs and calculating relative utilities, although the gap between the prevalence of diabetes in urban and rural areas is decreasing yearly (26, 27). However, medical services, medical equipment, and healthcare systems in rural areas of China still differ significantly from those in urban areas (28). The direct non-medical costs (e.g., transportation, accommodation, etc.) and indirect costs (e.g., lost wages, etc.) required by rural residents for disease diagnosis and treatment were higher, which was the principal explanation why the costs of the three screening strategies in rural areas were higher than those in urban areas in this study. Additionally, due to factors such as literacy and health education, rural residents were found to have less awareness of self-monitoring of blood glucose, poorer adherence to treatment, and a lower rate of attainment of glycemic target. Consequently, these factors resulted in a higher risk of diabetes-related complications, consistent with the lower health utility values in rural areas compared with urban areas in this study.

4.2 Sensitivity analysis confirms the stability of the study results

Because the parameters such as costs, transition probabilities and utility values required for this study were obtained from relevant cohort studies, cross-sectional studies, and cost-effectiveness analysis studies in China and abroad, one-way sensitivity analysis and probabilistic sensitivity analysis were performed for both urban and rural models to assess the effect of changes in input parameters on the study results. In the model of POCT HbA1c compared with FCG and venous blood HbA1c, the results of this study were stable when the parameters varied within the reference range or ±20%, either when a single parameter changed or when multiple parameters changed simultaneously.

In the model comparing venous blood HbA1c with FCG in rural areas, the one-way sensitivity analysis suggested that the ICUR value was greater than the WTP threshold and the results were unstable; the main influencing factors included the discount rate, prevalence of type 2 diabetes in rural areas and transition probability of multiple complications. The probabilistic sensitivity analysis showed that the probability of venous blood HbA1c had cost-effectiveness in urban areas was 30%, and the probability in rural areas was only 9.1%. Therefore, factors such as geographic location, local financial situation, and resident compliance needed to be considered when making the choice of venous blood HbA1c or FCG.

4.3 Current status in the application and quality control of POCT HbA1c

Currently, POCT HbA1c has being used for type 2 diabetes screening in Japan (13) and many European regions (12), whereas it is not widely used in China. This may be related to the lack of relevant Chinese studies on POCT HbA1c and the uncertainty of its accuracy and quality control. To this point, a meta-analysis

found that POCT HbA1c results showed an overall negative bias and that the diagnostic cut-point values differed between regions and populations (29). With continued progress in the development of the POCT assay technology, small-sample Chinese studies have confirmed that POCT HbA1c showed good accuracy, precision and resistance to interference (30, 31). One example from 2017 reported on 842 community-based physical examinations that demonstrated POCT HbA1c testing diagnosed diabetes with a cut-point value of 6.14% and an AUC of 0.911, highly accurate and precise (15). However, compared with European countries, there are relatively few clinical studies on POCT HbA1c in China.

4.4 Strengths and limitations

The study is the first to conduct a cost-effectiveness analysis of POCT HbA1c in China. Three screening strategies were investigated: POCT HbA1c, FCG and venous blood HbA1c. They were constructed from a social perspective, and their long-term effects on the duration and economics of type 2 diabetes were evaluated in urban and rural areas of China. In the Markov model, we set up six major complications of type 2 diabetes, including microvascular complications (diabetic kidney disease, diabetic foot ulcers, diabetic retinopathy, and diabetic peripheral neuropathy) and macrovascular complications (stroke and cardiovascular disease), with assumptions about disease progression, including end-stage renal disease, amputation, and blindness. Also, we included an analysis of multiple complications, considering that many patients in the clinic are accompanied by more than one complication. Compared with previous studies of POCT HbA1c (13), this model was more comprehensive and a closer approximation to reality. The intent was to mimic real-life clinical practice and management in rural and community healthcare organizations in China.

There are limitations to our study. First, the models constructed in this study were relatively simplified economic models, despite including comprehensive assumptions about different complications and progression states of type 2 diabetes, different interventions following screening that could impact the development and course of the disease, morbidity and mortality of different complications, probabilities of interconversion or combination of complications, and costs in the real world. Second, because some model parameters such as the transition probability and cost of multiple complications have not been studied in China, we used data results from large prospective cohort studies derived from other countries. For the status of multiple complications, we set the same transition probability and cost due to limited study data. Third, because the utilities of type 2 diabetes and complications are related to subject compliance, the model set the compliance of the population at 100%, recognizing the actual compliance of the real-life population might be quite different. Finally, there were many brands of POCT HbA1c devices in the Chinese and international markets, and the diagnostic cut-point values and accuracies of different brands of devices are different, which could influence the study results.

5 Conclusion

In summary, this study suggested that POCT HbA1c was cost-effective for type 2 diabetes screening in both urban and rural areas of China, which could be considered for future clinical practice in China. Factors such as geographic location, local financial situation, and resident compliance needed to be considered when making the choice of venous blood HbA1c or FCG.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Ethics Committees of West China Hospital. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

QS: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. XX: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. LW: Investigation, Methodology, Project administration, Supervision, Validation, Writing – review & editing. LG: Investigation, Methodology, Supervision, Validation, Writing – review & editing. YH: Investigation, Methodology, Supervision, Validation, Writing – review & editing. YZ: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1438945/full#supplementary-material

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Drivers, adaptations, and public impacts of hospital closures: implications for policy

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A concerning number of hospitals have closed in the US in recent years and there are many other hospitals that are at significant risk of closure in the coming years. The COVID-19 pandemic magnified the trend of hospital closures, raising further concerns about the potential impacts of hospital closures and the important need for devising policies that can mitigate them. To devise such policies, however, we first need to better understand the main drivers, potential adaptations by providers, and the widespread public impacts of hospital closures. We also need to recognize various changes in care delivery modes and related practices. Understanding these complex issues can allow policymakers to shift their focus from the narrow scope of "access to care," and instead take into account various other consequences of hospital closures that are currently largely overlooked but need to be part of policy discussions.

KEYWORDS

hospital closures, public health, public policy, health services, hospital management

1 Introduction: main drivers of hospital closures

There are various drivers that contribute to the increasing trend of hospital closures in the US. The first driver is related to the financial challenges. Specifically, hospitals operate on tight margins and face financial pressure from a variety of sources, including reduced reimbursement rates from government payers like Medicare and Medicaid, uncompensated care for uninsured patients, and rising costs for supplies, technology, and labor. Financial challenges are particularly acute for rural hospitals, which typically have smaller patient populations and struggle to attract and retain physicians. Financial challenges were exacerbated for many hospitals during the COVID-19 pandemic, in part because they had to stop more profitable services (e.g., elective surgeries) and shift their resources toward less profitable COVID-19 patients.

The second driver is related to changes in healthcare policy. Healthcare policy changes—at the state or federal level—can have a significant impact on hospitals. For example, changes to Medicare reimbursement rates or eligibility criteria can affect hospital revenues. In parallel, states' Medicaid expansion decisions can affect the number of insured patients their hospitals serve, and hence, are known to be directly related to hospital closures (1, 2). The US government, however, has had a few mechanisms in place to provide funding for hospitals facing challenging circumstances. Examples include the Disproportionate Share Hospital (DSH) payment that supplements the cost of uncompensated care, the Critical Access Hospital (CAH) program aimed at covering the high fixed costs that rural hospitals often face, and the Consolidated Appropriations Act that introduced a new hospital type termed "rural emergency hospital" (REH).

These funding mechanisms, however, have been subject to various alterations (3, 4). For example, recent healthcare reforms have attempted to cut the DSH fund by $35.1B

between FY2017 and FY2024, and there have been various efforts to make the CAH program's eligibility stricter (3). The COVID-19 pandemic, however, forced the US government to increase its support for hospitals that have been struggling. Specifically, the government provided additional federal support such as the Coronavirus Aid, Relief, and Economic Security (CARES) Act, devoting $175B for providers hit hard by COVID-19 (3). The Department of Health and Human Services has also expanded the Medicare Accelerated and Advance Payment program—a loan program that helps hospitals with disruptions in cash flow (3). These supporting mechanisms have enabled some struggling hospitals to "take a breath", enabling them to acquire essential equipment, recoup lost revenues, and most notably, stay open. Nevertheless, funds are restricted and largely constrained. What is more, the US government in some cases—especially with regards to stimulus packages such as CARES Act—has not been able to implement effective mechanisms that ensure the funds go to hospitals that are at utmost need—and not the wealthier ones that did not face significant financial or operational challenges during the pandemic. Similarly, the recent Consolidated Appropriations Act that made over 1,500 rural hospitals eligible for funds through a REH designation—including more than $3.2 million in 2023 as additional facility payments—could help rural hospitals at risk of closure (5, 6), but has introduced various unintended consequences such as worsen access, increased rejected transfers and delays in care due to capacity limits, higher levels of care fragmentation, and reduced workforce across inpatient and outpatient settings (5).

The third driver of hospital closures is a rapid growth in industry consolidation and vertical integration. By and large, the healthcare industry has been consolidating at a rapid speed, with more powerful hospital systems acquiring smaller, independent hospitals. Similarly, medicine in the US is becoming more vertically integrated with larger hospitals acquiring independent physician practices (7). These concerning changes can lead to closures of smaller facilities that are no longer financially viable or competitive, or those that are deemed redundant by the larger healthcare systems.

The fourth driver is related to the demographic shifts. Changes in population demographics can also affect hospital viability in significant ways. For example, as populations age, there is an increased demand for certain types of healthcare services (e.g., long-term care), while other services may face a decreased demand. These changes in demand, caused by changes in population demographics, create significant issues for some hospitals, pushing them to close entirely or at least shut down some of their services. Some of the lock-down policy interventions implemented by the US government during the early stages of the COVID-19 pandemic [see, e.g., (8)] also reduced the mobility of some patients, making them less likely to travel to hospitals, changing the demographic portfolio of patients they serve.

Demographic shift among providers is also another contributing factor to some hospital closures. Specifically, in smaller and rural hospitals, there is a considerable trend of the physician workforce aging. This, coupled with high rates of provider turnover, poses significant challenges for such hospitals. For example, when a key hospital specialist (e.g., an obstetrician, general surgeon, or orthopedic surgeon) is lost due to retirement or difficulties in retaining them, the impact on the hospital's financial health can be severe, exacerbating its vulnerability to closure.

The fifth driver is the tendency of some patients, especially in rural areas, to not seek care at their closest hospital, a phenomenon known as "hospital bypass." Some recent analysis indicates that about 50% of discharges from hospitals related to patients that bypass their closest hospital (9). This bypass behavior of patients, perhaps in hope for receiving higher quality of care, leads to reduced demand in local rural hospitals, imposing significant financial distress and spiked risk of closure (10, 11).

Finally, there are various technological advances that affect care delivery models and hospital operations. For example, the rise of telemedicine post COVID-19 has made it easier for patients to receive care remotely, reducing the need for in-person visits and potentially leading to lower demand for certain types of hospital services. Mobile Health (mHealth) technologies that are now more common than before—thanks to advancements in smart phones, sensors, and Internet of Things (IoT) enabled devices—have also reduced the need for patients to go to hospitals, thus, reducing the demand for some of their services (12). And a reduction in demand often has important revenue related consequences for hospitals, pushing some closer to closure. Beyond the impact on the size of the demand, however, technological advances along with various payment reforms, have created changes in the type of demand for hospital services. In particular, hospitals have faced significant shifts in demand from inpatient to outpatient care, impacting their revenues and risk of closure.

While the focus of this piece is the US, it is useful to also note that the equivalent of some of these drivers exist in other countries. Nonetheless, the US healthcare system is significantly different from that of many other countries, and thus, comparisons might not be meaningful. For example, the US healthcare system is strongly influenced by technological advancements in treatments, pharmaceuticals, and medical devices that often come with high R&D and implementation costs. In the US, these costs are typically passed on to patients, insurers, hospitals, and the healthcare system more broadly. In the single-payer healthcare systems, however, prices are more strongly negotiated, resulting in less direct increases in the costs. In the mixed public-private systems, a diverse set of government regulations, negotiations, and market mechanisms are employed, which also alter some of the driving forces discussed above.

Providing correct mechanisms for financial support to struggling hospitals, policy changes, incentivizing suitable integrations and mergers in support of less stable hospitals, and expanding telehealth services to areas affected by hospital closures (or making use of community-based healthcare solutions in such areas) are among the strategies that can mitigate the impacts of some the drivers of hospital closures. However, in addition to understanding these drivers, to better comprehend the impact of hospital closures, and thereby design more effective policies, we also need to consider how providers—remaining hospitals and physicians—adapt when a hospital closes. And this is where findings from various recent studies can particularly help.

2 Nearby hospitals adaptation to hospital closures

When a hospital closes its nearby hospitals face the challenge of handling a sizable demand spike, since the needs of patients of the closed hospital are added to their typical workloads. So how do such hospitals adapt to the spike demand?

A recent large-sale analysis of over 14 million patient visits across the US (4) suggested that the nearby hospitals on average improve their operational efficiency. That is, without adding much additional capacity, they end up serving more patients. However, they do so via a *speed-up* response. That is, by reducing their average service duration instead of lowering their average bed idle time. What is more, this speed-up response negatively affects some aspects of quality of care such as the 30-day mortality rate (4).

These "spillover" effects of hospital closures are largely overlooked, but are highly important to take into account by policymakers and other authorities who want to mitigate the negative consequences of hospital closures. This is especially important, considering that evidence suggests that the nearby hospitals cut some value-added care delivery steps in response to facing the spiked demand caused by a closure (4).

Moreover, it is equally important to note that these spillover effects of hospital closures are highly heterogeneous. For example, nearby hospitals that are often considered more desirable (e.g., high-quality, urban, and teaching hospitals) tend to experience more prominent spillover effects on their operations. Notably, these heterogenous effects often magnify social disparities by enlarging the existing efficiency gaps between the more and less desirable hospitals (3, 4).

Finally, nearby hospitals might alter some of their protocols and deviate from preferred patient-provider assignments in response to the increased demand. Hospitals operations in the US as well as patient outcomes and expenditures are already affected by such deviating behaviors (13), and hospital closures might intensify them.

3 Physicians adaptation to hospital closures

When a hospital closes, physicians who practice there may face a variety of challenges as they seek to adapt to the new circumstances. Besides understanding how hospitals respond to closures, it is vital to comprehend the response from physicians.

Overall, adapting to a hospital closure can be a complex and challenging process for many physicians, requiring a significant amount of patience, flexibility, and resilience, among other traits or behaviors of the physicians. Some of the most common ways for physicians to adapt—besides relocating to a new area or commuting to a different hospital—include exploring alternative practice models, considering opening a new practice, and retiring or leaving the profession.

Specifically, many physicians may explore alternative practice models, such as telemedicine or concierge medicine, that allow them to provide care outside of the traditional hospital setting. New internet-enabled technologies also allow them to be hired in location-independent roles, including serving as a tele-triage physician (14).

To adapt, some physicians may consider opening their own practice or joining a small group practice. This can provide greater autonomy and control over their work, but also comes with the burden of managing a business. In addition, for some physicians, a hospital closure may be a signal to retire or leave the profession altogether. This can be particularly true for physicians who are close to retirement, or those who are reluctant to start over in a new healthcare system. These changes can significantly alter the supply side of healthcare.

But can physicians easily keep their career going after their hospital closes? In some cases, there may be many opportunities available, and physicians may be able to transition to a new hospital or practice without much hassle. In other cases, it may be more exigent to find new employment opportunities, particularly in rural areas where there may not be any other hospital nearby. The ease of switching also depends on the current setting in which a physician is practicing. For example, some physicians already use telemedicine, tele-triage, or other related technological advancements to serve multiple hospitals, and hence, they may not face much trouble when one of their hospitals closes.

In addition, physicians' professional network and financial resources can also play a significant role in how they can respond to their hospital being closed. Thus, there are various individual level differences that can play a role as well.

It is also essential to note that hospital closures can have ripple effects throughout the healthcare system, and the impacts may not be limited to specific specialties. For example, primary care physicians who refer patients to the hospital for specialty care may have to refer them to different hospitals after a closure, which can impact their patient relationships and continuity of care.

Nonetheless, hospital closures often affect those specialties that rely heavily on hospital-based services more than others. For example, some hospitalists often work exclusively in the hospital setting and do not have any private practice outside of the hospital. When a hospital closes, hospitalists may have to find new jobs or relocate to another hospital. Emergency medicine physicians also often work primarily in a hospital emergency department (ED), although even in that case there are various inter-physician differences among them, including significant difference in key performance measures such as adjusted average length of stay (15), resource utilization, and admission rate (16, 17). When a hospital closes, its ED also closes, forcing its ED physicians to relocate to another hospital.

Another group of physicians that are often affected by closures are anesthesiologists who provide anesthesia services for patients undergoing surgery or other procedures in the hospital. When a hospital closes, there may be fewer opportunities for anesthesiologists to practice in the area due to the nature of their specialty. Similarly, hospital closures often affect OB/GYNs providers in charge of women during pregnancy, childbirth, and postpartum. When a hospital with a labor and delivery unit closes, OB/GYNs may also need to relocate. And the relocation of physicians can change demand vs. supply ratios, mainly because the patients move their healthcare needs "locally", while physicians

might move out of state or relocate to further locations. Such changes in demand vs. supply can, in turn, have various large-scale negative impacts.

4 Conclusion

Despite various available studies (see, e.g., (18) for a review), more research is needed to get a better picture of the entire impact of hospital closures. But what we know is that their impact goes well-beyond the typical discussion on patients' access to care. Notably, hospital closures have serious impacts on providers—physicians and the nearby hospitals. Limiting the discussion to access to care is not only a disservice to providers and the entire healthcare sector, but could also mislead potential policy solutions.

For example, understanding that a hospital closure can induce speed-up behavior in a nearby hospital, and that this speed-up behavior in turn can negatively affect the quality of care delivered there, offers a new policy perspective. Should policymakers direct resources to bail out hospitals that if closed would impact access to care, or should they instead bail out hospitals that if closed would significantly impact the quality of care of their nearby hospitals? Similarly, understanding the adaptation by physicians can encourage policymakers to direct resources to bail out hospitals that if closed would create large regional demand vs. supply mismatches. And there are various policy levers beyond bailout as well. For example, realizing that a hospital closure can induce speed-up behavior among nearby hospitals suggests yet another effective policy lever: monitoring length of stay changes post-closure among nearby hospitals. Overall, these aspects of hospital closures have been largely overlooked and more research is needed to provide policymakers with actionable insights.

Finally, shedding light on the less understood but widespread impacts of hospital closures can lead to better data collection efforts—a vital requirement for more intelligent policy designs. Given the increasing attention to campaigns aimed at collecting and publicly reporting hospital data, such as those in public and private public reporting efforts (19, 20), researchers and policymakers can focus on collecting more relevant data useful for predicting closures. This will enable them to make use of relatively accurate estimates of closure risks and obtain more actionable insights.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

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Relevant factors affecting nurse staffing: a qualitative study from the perspective of nursing managers

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Objective: To understand the current situation of nursing manpower allocation, explore the factors affecting nurse staffing, improve nurse staffing level, and provide reference for better formulation of nursing human resources staffing standards.

Methods: A descriptive research method was used to conduct semi-structured interviews with 14 nursing managers. The data were analyzed and refined by content analysis. The sample size was subject to content saturation.

Results: Nine themes and twenty sub-themes of influencing factors for nursing staffing were identified across four levels: hospital level, department level, patient level, and nurse level.

Conclusion: Hospital and department managers need to comprehensively consider the factors of affecting nurse staffing. Adopting multidimensional optimization measures, improving relevant systems, optimizing nurse structure, and establishing flexible and mobile nurse database to cope with public emergencies, so as to effectively improve nurse staffing and nursing service quality.

KEYWORDS

nurse staffing, nurse manager, semi-structured interviews, influencing factor, human resources

1 Introduction

The global nursing workforce shortage has been a major challenge in the medical field. In 2020, the World Health Organization reported a shortage of 5.7 million nurses and midwives (1). By the end of 2022, the total number of health workers in China was 14.411 million. Among them, the total number of registered nurses is 5.224 million (2). Compared with the 2025 China nursing career planning target, there is still a gap of 276,000 (3). The number of registered nurses in China in 2022 is 3.17 per 1,000 population, which is far lower than the global median density proposed by WHO (4.86 per 1,000 population) (4). In the evolving healthcare sector, ensuring optimal nurse staffing remains a key issue in hospital administration

and nursing management (5, 6). Adequate nurse staffing is critical not only to provide high quality patient care, but also to maintain nurse job satisfaction and reduce turnover (7, 8). However, the factors that influence nurse staffing are multifaceted and complex, including a range of variables from institutional policies to the characteristics of individual nurses. At present, researchers mainly focus on quantitative studies on nurse staffing and nursing quality, patient outcomes and nurse outcomes (9, 10). However, there are few qualitative studies on the influencing factors of nurse staffing. Nursing managers play a key role in staffing decisions, pay close attention to day-to-day operational dynamics and challenges, and are uniquely positioned to provide insights into the various factors that affect nurse staffing (11). Therefore, this study aims to explore the influencing factors of nurse staffing through the perspective of nursing managers, and through in-depth interviews and thematic analysis, reveal the human resource challenges and considerations faced by nursing managers in their efforts to ensure appropriate nurse staffing levels. The results of this study will help develop more effective staffing strategies and policies, ultimately improving the quality of care provided to patients and improving the working environment for nurses.

2 Research objectives

This qualitative study explores the influencing factors of nurse staffing. Two nursing managers were selected for pre-interview, and the final interview outline was revised according to the feedback of the pre-interview. See Table 1 for details.

3 Materials and methods

3.1 Participant recruitment

From December 2023 to February 2024, nursing managers in a Grade 3 hospital in Guangdong Province were selected as interview subjects by purpose sampling method. Inclusion criteria: (a) Engaged in clinical work ≥10 years; (b) Engaged in management work ≥3 years; (c) have intermediate or above professional titles; (d) Informed consent and voluntary participation in this study.

3.2 Data collection methods

The development of the interview outline was based on the research objectives and a review of relevant literature, following a systematic process (12). An initial draft of the interview guide was formulated to focus on the research theme. This draft was refined through discussions in project team meetings. Before the formal interviews, two nursing managers were invited to participate in pilot interviews, and since no further revisions were needed, the pilot interview data were included in the subsequent analysis. The qualitative research involved conducting semi-structured, in-depth face-to-face interviews with the participants. Before each interview, one researcher (LGG) obtained informed consent from the interviewees, explaining the purpose, methods, and content of the interview. The interviews were recorded and noted, and were conducted in the interviewee's office to ensure privacy. To protect the confidentiality of the participants, two researchers (LGG and WWE) were responsible for questioning and recording, respectively, using pseudonyms N1 to N14 instead of real names. The interviews were conducted in easily understandable language, encouraging participants to express their feelings and thoughts fully. Active listening, clarification, and probing techniques were employed, along with noting non-verbal cues. Each interview lasted between 30 and 60 min, with an average duration of 39 min.

TABLE 1 Interview outline.

Question
1 What is the current situation of nursing staffing in your ward? And what do you think of the current situation of nurse staffing?
2 What problems do you encounter when staffing? And how did you solve these problems?
3 What do you think are the factors that affect the staffing of nurses?
4 What are your suggestions for nursing staffing?

3.3 Data analysis methods

Data collection and analysis in this study were conducted simultaneously. Within 48 h after each interview, the recordings were transcribed verbatim, and the non-verbal information recorded during the interviews was integrated into the documents, forming complete interview transcripts. We used thematic analysis to analyze the data (13), organizing the materials with NVivo Plus 11 software. Throughout the analysis process, the two researchers (LGG and WWE) maintained an open and neutral attitude, repeatedly reading the transcripts and non-verbal notes. By continuously comparing and inductively analyzing the data, we extracted themes to gain a deeper understanding of the participants' actual meanings. Text from individual interviews was divided into meaning units that were condensed and coded. The themes in the table were derived from the initial codes, with similar codes grouped into subcategories and categories, which were then further organized into themes (14). The first author identified the initial codes, while the other authors reviewed the coded interview samples. Any disagreements regarding themes were resolved through discussions among all authors until a consensus was reached.

4 Results

4.1 Sample size

The sample size was by information saturation (15). Finally, a total of 14 participants participated in this study, among which 13 were female and 1 was male, and the average age of all participants was 45.86 years old (33 ~ 52 years old). The average duration of clinical work was 25.57 years (11–23 years) and the average duration of managerial work was 11.21 years (4–16 years). The demographic characteristics of participants are shown in Table 2.

4.2 Hospital level

4.2.1 Imperfect policies and systems

Decisions made by hospital management based on national policies, such as establishing standards for bed-to-nurse ratios in each

TABLE 2 General data sheet for participants.

ID	Gender	Age	Educational level	Professional title	Clinical working time	Manage working time
N1	Female	33	Bachelor	Supervisor nurse	11	6
N2	Female	52	Bachelor	Supervisor nurse	34	16
N3	Female	46	Bachelor	Chief nurse	21	12
N4	Female	45	Bachelor	Deputy chief nurse	21	10
N5	Female	48	Bachelor	Deputy chief nurse	21	10
N6	Female	44	Bachelor	Supervisor nurse	21	9
N7	Female	50	Bachelor	Deputy chief nurse	22	15
N8	Female	47	Bachelor	Deputy chief nurse	21	12
N9	Female	51	Bachelor	Deputy chief nurse	23	15
N10	Female	50	Bachelor	Supervisor nurse	23	14
N11	Female	42	Bachelor	Deputy chief nurse	18	4
N12	Male	39	Bachelor	Deputy chief nurse	16	9
N13	Female	47	Bachelor	Supervisor nurse	21	12
N14	Female	48	Bachelor	Deputy chief nurse	22	12

department, inspection systems, training and promotion mechanisms, significantly impact nurse allocation. However, N12 highlights that for specialized departments like emergency care, there lacks a unified allocation standard in China (16), which complicates nurse allocation levels to some extent. Several respondents in the study noted limitations in current nurse staffing due to rigid adherence to bed-to-nurse ratios that often fall short, thereby compromising adequate staffing levels. Furthermore, the imperfect inspection, promotion, and training systems in the face of a complex and evolving clinical environment constrain nurses' workload and career advancement opportunities, affecting both stability and quality of nursing care.

4.2.2 Insufficient manpower reserve

The hospital's human resource reserve directly influences the quantity and quality of nurses, as well as the hospital's capacity to address staffing shortages, temporary needs, and emergencies. Respondents in the study also noted that due to insufficient or lacking hospital manpower reserves, even submitted personnel demand applications often remain unresolved.

4.3 Department level

4.3.1 Department characteristics

In the rational allocation of nursing human resources, it is necessary to consider a variety of factors, such as the department's patient conditions, department size, bed turnover, workload, and the need for specialized nursing. For instance, departments like emergency, intensive care, and surgery require nurses with specific professional skills and knowledge to ensure patient safety and effective treatment outcomes.

4.3.2 Cost-effectiveness driven nurse staffing

Reasonable manpower cost control can be in to ensure the quality of care under the premise of optimizing the allocation of resources, improve the efficiency of the cost. Appropriate labor cost control of department, fair and reasonable scheduling system, by ensuring reasonable salary, meet the demand of nurses reasonable help stabilize the nurse team, reduce turnover and maintain the continuity and stability of the nursing work, at the same time maximize the cost-effectiveness of department, ensure quality of nursing service.

4.3.3 Cultural construction of the department

Department culture construction is one of the important factors affecting the allocation of nurses, including good working atmosphere and teamwork, effective communication and mutual understanding, and staff care. A good department culture construction can improve the satisfaction and stability of nurses, and ensure the efficiency and high quality of nursing work. In the study, respondent N1 also said that a good working atmosphere in the department would alleviate the original shortage of manpower.

4.3.4 Multi-level recognition and support

Nurses occupy a large proportion in the department and play an indispensable role. Recognition at the department level, including but not limited to the head nurse and department director, as well as the recognition and support from doctors for the work of nurses, can not only enhance nurses' job satisfaction and loyalty but also significantly improve the efficiency and quality of nursing care. This influence helps optimize working conditions for nurses.

4.4 Patient level

4.4.1 Patient profile

With the rapid development of social economy, the demand for nursing services is gradually increasing. The basic situation of patients, including the number of patients, the complexity of the disease, the self-care ability of patients and the patient's needs, which will virtually affect the workload of nurses, and therefore put forward requirements for the staffing of nurses.

4.5 Nurse level

4.5.1 Challenges in nursing human resources

The shortage of nurses is a significant issue in nursing human resource management, profoundly affecting nurse staffing. Insufficient nursing staff can lead to a decline in the quality of nursing services, failing to meet patient care needs, and thereby impacting treatment outcomes and patient satisfaction. Respondents to the study indicated that this shortage is expected to persist in the short term. Currently, nurses face high workloads and pressure, with long-term overwork increasing their physical and psychological burden, reducing work efficiency and quality, and leading to higher turnover rates. This exacerbates the challenges in nurse staffing.

4.5.2 Nursing professional development

The structure of nurses is an important part of human resource management, including the age, work experience, title, comprehensive ability and specialized skills of nurses. Optimizing the structure of nurses can promote the staffing of nurses. Provide continuous professional training and career development opportunities for the nursing team, including advanced studies, promotions, and specialized training. These initiatives will improve nurses' professional skills and career satisfaction, enhancing their willingness to stay in the department and their overall stability (see Table 3).

5 Discussion

For additional requirements for specific article types and further information please refer to "Article types" on every Frontiers journal page. From the perspective of nursing managers, this study discussed the relevant factors affecting nurse staffing, mainly from four levels: hospital, department, patient and nurse level.

The results of this study indicate that nurse staffing is related to the imperfection of hospital policies and systems, the lack or insufficiency of manpower reserves, and the control of nurse manpower costs. The formulation of policies related to nursing human resources can play a crucial role in the number of nurses. On the one hand, although China has formulated many standards, principles and plans for staffing (17–20), but at present, most medical institutions in our country still adopt a single number of beds for human staffing, ignoring the differences of condition, disease, service quantity, etc., which makes it difficult to meet the clinical practical needs of nursing human resources. On the other hand, the participants indicated that the hospital did not reserve talents or had insufficient reserves at present, and the study found that public emergencies would have a certain impact on the staffing of nurses, and the reasonable establishment of a mobile nurse base could make up for the shortage of manpower to a large extent in crisis situations (21).

At present, there is no legislation on nurse staffing in China, but there are a few areas (10, 22, 23), such as Victoria or Queensland in Australia and California in the United States, have made the nurse–patient ratio mandatory, and scientifically found that this measure is beneficial to patients and healthcare systems. Belgium is also reforming its nursing staffing policy and using part of its budget to hire non-nursing staff to alleviate the shortage of nurses, while India is making further efforts to revise the standards of the nurse-to-patient ratio. Yet labor costs dominate hospital budgets. They are easy targets for cuts to offset other expenses (24). The financial budget of a hospital on the cost of nursing manpower will directly affect the number of nurses, resulting in the imbalance of the nurse-to-patient ratio, and increasing the work pressure and load of existing nurses (25). In the future, when developing safe and reasonable nurse staffing, it is necessary to comprehensively consider the control of nurse labor cost and solve the problem of baseline nurse staffing, so as to better cope with the fluctuation of nurse nursing demand among patients (26, 27).

In addition, the shortage of manpower reserve makes it difficult for hospitals to quickly deploy enough nurses in the face of emergencies (such as epidemics, natural disasters, etc.), which affects the timeliness and effectiveness of nursing work. First of all, in order to actively and effectively respond to public emergencies and other emergency events, it is necessary to establish a mobile nurse team. At the same time, it is necessary to strengthen the hospital's leadership of the nurse team and improve the emergency level of the nurse team. Secondly, the recruitment process of new nurses should be accelerated, and the relevant training mechanism should be optimized to ensure that new nurses can quickly get on the job and adapt to the work needs. Finally, establish reasonable vacation and prepare class arrangements, to ensure that the nurse has enough during the period of vacation or sick leave substitute nurses to fill the gap, to ensure the safety of patients and the high quality nursing service.

The results of this study show that the staffing of nurses is related to the department characteristics, cost-effectiveness driven nurse staffing, department culture construction and multi-level recognition and support. Nurses with affected by the characteristics of the various specialist departments for college work, care needs and technical differences, nurse need to change accordingly, in order to ensure safe and effective nursing service. The control of nurse labor costs varies between departments and hospitals due to differing economic benefits. It is crucial to balance the relationship between existing nurse staffing and costs. A limited department budget can affect the hiring of additional nurses or the ability to increase nurses' salaries, directly impacting nurse staffing levels. Implementing a fair and reasonable scheduling system ensures that each nurse receives adequate work and rest time, preventing overwork or underwork. This can improve job satisfaction and work efficiency, thereby reducing nurse turnover rates and fatigue (28).

Additionally, fostering a positive departmental culture is also essential. Nurses' working environment and atmosphere, and leadership style can affect nurses' turnover intention, thus further affecting the staffing level of nurses and the quality of nursing work by affecting nurses' turnover intention (29–31). Active teamwork, effective communication, and mutual understanding are crucial factors in optimizing nurse allocation and improving the quality of nursing services. Good teamwork and effective communication streamline workflow, reduce redundant tasks and communication errors, and enhance nursing efficiency (32, 33). Mutual understanding and trust among team members facilitate knowledge and experience sharing, promoting both individual and team skill development. A well-functioning department resembles a warm, supportive family, which requires managers to show concern and care for nurses, focusing on their physical and mental health needs. This helps alleviate work pressure, strengthens colleague relationships, and enhances team stability. Multi-level recognition and support from department directors, head nurses, doctors, and patients serve as key motivators for nurses, reinforcing their commitment and sense of value in their

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TABLE 3 Influencing factors of nursing staffing.

First-level themes	Second-level themes	Nursing manager quote
Hospital level		
Imperfect policies and systems	Lack of unified standards for emergency nurses	N12:"There's no national standard for emergency staffing, and we have talked about it, but there's no clear target for staffing, so nurse staffing levels are definitely going to be affected."
	Limitations of bed-to-nurse ratio standards	N2:"the current department is not up to the standard of the hospital's bed-to-care ratio… Even with the deployment of mobile nurses and nurses from other departments, they are still unable to fill the gap."
		N9:"Our department is the largest department in the hospital, according to the designated bed-to-nurse ratio, we need to reach 39 nurses, but currently there are only 35, and when we add the nurses who resign, retire or take maternity leave, the department's manpower is very tight."
		N13:"Relatively speaking, our department did not meet the hospital's standard for bed-to-nurse ratio. Our department is unique in that nurses are also assigned to the respiratory center and outpatient department, resulting in fewer nurses available for the wards and tighter manpower resources."
		N14:"Not every department in our hospital has established a standard for nurse-to-bed ratio, but currently, we are unable to meet this ratio and face insufficient manpower."
	Frequent checks, and imperfect promotion and training systems	N3:"Because A Class III Grade A hospital, often face too many examinations, including our own nursing department, the hospital's, and the state's examinations, minimizing the pressure of such examinations on nurses, and really give the nurses back to the patient, I think the nurse is actually very willing."
		N9:" In the area of management, I think it is possible to relax the training conditions for this specialist nurse?… Such a situation exists in our department, the ability can be reached, but the academic degree cannot be reached…"
Insufficient manpower reserve	Inability to cope with staff shortages in emergency cases	N5:"During the COVID-19 epidemic, many nurses have gone out, they can only ensure safety, and the rest cannot be managed at all… In the case of extreme manpower shortage, only basic work can be ensured "
		N8:"But now, when a member of the department is sick, or there are emergencies, or even nurses need to be placed on leave, in such cases, other nurses have to work overtime because there is no other staff to supplement."
	Inability to timely address manpower shortages	N6:"I have applied to the head nurse of the department, but the head nurse answered that many departments are short of staff, which may be difficult to solve, so I did not apply to the above, indicating that this problem may indeed exist in the past two years."
		N2: "There is no way, you can only wait for a new group of nurses, or in fact, the hospital has mobile nurses, but because of the two-way selection policy, many nurses will not choose the workload of the department, it is still difficult."
Department level		
Department characteristics	Specialty nursing needs and technology	N1: "Our specialty has a higher risk of mental violence, which affects nurse staffing. Considering the risk factors, it is best to have a mix of male and female nurses. However, there are very few male nurses, resulting in a greater demand for them."
		N11: "The current staffing is based on existing manpower, but the ICU is basically a very serious patient, and the condition can change at any time… Therefore, manpower will be taken into account "
		N12:"Because our emergency department operates under fixed conditions, our staffing requirements differ significantly from other departments. I need to consider many additional factors."
	Departmental work	N5: "This time will be better, because it is near the New Year, and our department basically receive more elective surgeries… So it obviously seems that during this period, the patient beds are a little empty, so the manpower is not so tight "
		N9: "It will also take into account the working hours, and allocate personnel to work according to the situation of the time period… And gynecological preoperative preparation is very time-consuming, and each department has different specialty characteristics."

(Continued)

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TABLE 3 (Continued)

First-level themes	Second-level themes	Nursing manager quote
Cost-effectiveness driven nurse staffing	Control of nurse labor costs	N1:"In accordance with the hospital provisions of the bed protection ratio standard, the department is currently able to operate, because there are too many manpower, the department's income is not high, then everyone's income will be lower… So the current manpower will have little impact on people's income."
		N3:"As nursing manager, I also do not want too many of my nurses… It is good to be able to meet the rotation of departments."
		N11: "Due to better departmental economic performance, the department bonuses are relatively high, contributing to higher job satisfaction among the nurses."
	Equitable and rational scheduling system	N1: "In terms of scheduling, fairness is a priority in our department due to varying workloads and flexible assignments, aiming to achieve a balanced approach."
		N2: "Our department has maintained a rotating leave system for a long time, emphasizing the importance of fairness and considering each nurse's needs when scheduling."
		N6: "When it comes to scheduling, we prioritize balance and fairness. It's not about one nurse's workload preventing others from taking leave; rather, we strive to ensure equitable opportunities for all."
		N13: "In our department, vacation scheduling adheres strictly to established rules. Everyone is conscientious about following these rules, ensuring a humanized approach to scheduling."
Cultural construction of the department	Positive department atmosphere and team collaboration	N1:"The atmosphere of our department is very good. If a department has a strong cohesion, it is easier to overcome and solve any problems. Even in the absence of foreign assistance, we can also overcome the shortage of manpower."
		N11: "In the department, everyone helps each other, so that things can be dealt with quickly and the work efficiency is high. If you share a thing with everyone, the work will be much easier, so the working atmosphere is still very important."
		N13:"In fact, our nurses are not well treated at the moment, so team building is very important. First, as managers, we must ensure the physical and mental health of these nurses, but also put humanistic care for nurses first."
	Effective communication and mutual understanding	N1: "Colleagues need to truly understand each other. The higher the cohesion in a department, the more likely they are to spontaneously solve many problems."
		N6: "If a nurse in our department faces a significant issue at home, everyone works hard to help resolve it. I think this is a wonderful aspect of our team."
		N14: "Our nurses are quite aware. If one nurse is very busy while others are unresponsive, I, as a manager, will communicate and ask everyone to help. After doing this a few times, everyone naturally starts to help out voluntarily. So, timely communication is essential."
	Humanistic care in nursing	N5: "The atmosphere of our entire department I think is good, because if there is any problem, everyone will solve it together, I'm not gonna do this alone … I think the whole department has a good feeling, and the young people are also more motivated."
		N9: "To foster a positive working atmosphere, as managers, we should pay close attention to nurses' emotions, communicate promptly, and provide appropriate comfort when needed."
		N10: "We will hold some team building activities regularly, and we will care about the family status of nurses… So the atmosphere in the department is very good. It is also important for the team to draw on the strengths of the nurses and provide timely encouragement and support."
Multi-level recognition and support	Leadership of recognition and support	N3: "The daily work of clinical nurses is very hard, and we hope to increase the value of nurses… In fact, as managers, we are more respectful of the nurses' willing, and the head nurse is actually just an executor. We should learn to think from the perspective of nurses, so that nurses can reduce the mentality of boredom or resignation."
		N8: "When tasks are assigned to nurses within the department, it is important to acknowledge and appreciate their work. This recognition makes the nurses feel valued and supported."
		N14: "I believe recognizing nurses' work is crucial. It helps to utilize each nurse's strengths, fostering a sense of responsibility and allowing them to realize their self-worth."

(Continued)

TABLE 3 (Continued)

First-level themes	Second-level themes	Nursing manager quote
	Doctors' understanding and support	N3: "Doctors recognize and support the hard work and contributions of nurses. Nurses greatly need this validation and partnership, as it fosters a more enjoyable and positive work atmosphere."
		N6: "Then the director of our department is still very good and very supportive of our nursing."
Patient level		
Patients profiles	Patient volume and condition	N2: "The patient's condition must be taken into account, and another aspect is the patient's self-care ability."
		N3:"Depending on the number of patients, and also depending on the patient's condition, if the illness is very serious, maybe you can not just the original number of shifts, sometimes necessary, really have to start some programs to help…"
		N6:"In the past, our department primarily focused on hepatobiliary surgery, where patients generally had better prognoses and basic conditions. Now, the department has shifted to pancreatic surgery, which is the most complex and severe operation in general surgery, with patients often having the most complications and poorer overall conditions."
		N10: "According to the needs of the patients, the number of patients and the severity of the disease."
	The patient's needs	N4: "The first thing I will consider is the patient. I want to take good care of them by prioritizing their needs, which will guide our personnel."
		N8: "We must certainly prioritize the patient's needs. The patient's needs and safety come first, while also considering our existing manpower and the demands on our nurses."
		N9: "Of course, the staff should prioritize the patient, using the patient's needs as a guide."
		N13: "I believe the current schedule is more suitable for our families, especially in pediatrics. Unlike other departments, pediatrics requires a significant amount of work. Parental expectations are relatively high, and meeting these expectations is crucial."
		N14: "Staffing is available, but we must also consider patient needs. It's important to keep patients safe."
Nurse level		
Challenges in nursing human resources	Shortage of nurses	N2: "The shortage of nurses is also a problem facing the whole hospital. It's not that I cannot make up for you, but I just cannot make up for so many people to give you. It turned out that there were not so many people, and then it was distributed, but it was still not enough."
		N3: "Manpower is insufficient, I can only compress shifts… And the workload… That workload is transferred to the responsible nurses."
		N8: "In terms of quantity, the hospital's staffing standards are still not met, and the number of nurses is still not enough…"
		N10:"According to hospital standards, our department currently lacks two nurses, and one nurse is on maternity leave. If the two nurses who are nearing retirement also leave, the department will face challenges in scheduling shifts. Even if a new nurse is assigned to the department, she will require at least three months of training before being able to work independently."
	Nurses are overloaded	N7: "In terms of quantity, the hospital's staffing standards are still not met, and the number of nurses is still not enough…"
		N9: "Nurses report less rest, they cannot guarantee two days off a week, the second is busy work, long working hours, often delayed work… Then they will definitely complain, plus our low income, it will be even more dissatisfied, and there may be a problem in terms of turnover."
		N11: "Then there are some other, temporary specialist assignments in our department… Because I do not have a specialist nurse, I do not have a full-time nurse at the moment, so I have to deploy in this group… So this is a problem in our daily work, and sometimes it is a difficult management problem."

(Continued)

TABLE 3 (Continued)

First-level themes	Second-level themes	Nursing manager quote
Nursing professional development	Skill set of nurses	N2:"Then there are some other, temporary specialist assignments in our department… Because I do not have a specialist nurse, I do not have a full-time nurse at the moment, so I have to deploy in this group… So this is a problem in our daily work, and sometimes it is a difficult management problem."
		N4: "Years of work are the main thing, and the ability to work…"
		N5:"The first to consider the nurse's communication … And then, when appropriate, you have to look at the mix of people."
		N8: "The communication ability of nurses also depends on the personal ability and character of nurses."
	Personal career development	N7: "There are also some successors of head nurses and specialist nurses who should be encouraged to continue to upgrade their academic qualifications… The head nurse should also train these talents, otherwise, the department will not be able to find a successor when the head nurse retires, and we must train talents."
		N11: "I am encouraged by the opportunity for new studies and equal chances to explore, as this was my own experience. As long as you are eager to advance, I will provide more opportunities. It's important for young people to learn and broaden their perspectives on the world."
		N13: "I think the whole word… Encourage them more, take more classes, let them know that career prospects are better, reduce turnover."

work. However, the lack of necessary material and emotional support increases job burnout and affects nurses' intention to stay (34, 35). Therefore, in this challenging environment, it is crucial to optimize nurse allocation, enhance the quality of care, and ensure the stability of the nursing team. This can be achieved by improving the working environment and atmosphere, fostering team cooperation, formulating reasonable scheduling plans, and establishing effective communication and feedback mechanisms.

With the accelerated aging of China's population and the increasing prevalence of chronic diseases, the demand for long-term care and health management has risen significantly. The growing number of patients directly impacts the number of nursing staff needed in departments. A high patient load necessitates more nursing staff to ensure each patient receives adequate care. This situation poses a challenge for managers in nursing staff allocation, requiring flexible adjustments based on patient admissions and discharges to respond to fluctuating peaks and troughs.

Patients with complex conditions require higher levels of nursing skills and more hours of care, necessitating additional specialized nursing staff or more training and support. As patients' expectations for the quality of nursing care rise, departments need to increase their nursing staff to meet these expectations. A higher level of nursing expertise can improve patient satisfaction, delivering higher quality care and greater value (36). Therefore, when planning nurse allocation, managers should consider the number of patients, the complexity of conditions, and specific nursing needs. By conducting thorough evaluations and making flexible adjustments to the nursing team, managers can effectively address the needs of different patient groups and enhance the quality and efficiency of nursing services.

Nurses are the largest group in the medical and health system, occupying an irreplaceable position, and sufficient nursing staff is the premise and basis of rational allocation of nursing human resources. The shortage of nurses is a serious problem facing the world today (37, 38). The shortage of nurses will lead to the increase of nursing workload and labor intensity, resulting in a high turnover rate of nurses, and turnover intention is a predictive factor of turnover rate (39, 40). The turnover intention of nurses varies significantly among different countries. The turnover intention of nurses in South Korea was 18.8% (41), 22.5% of nurses in European countries expressed their intention to quit (42) and 43% of nurses in Lebanon expressed an intention to leave within one year (43). In China, the turnover intention of nurses in East China is 43% (44) and that of nurses in Guangdong Province is as high as 64.1% (40), which means that the turnover rate of nurses in China remains high, and the gap of nurses will further increase. Attracting and retaining the existing nurse workforce is critical to maintaining high quality patient care (26). Studies have shown that nurses are the foundation of patient safety and nursing quality, and higher nurses' satisfaction will bring better job performance, nursing quality and employee retention (34, 45). In addition, research shows that with adequate nurse staffing, good working environment and welfare benefits, nurses will have higher job satisfaction and lower turnover intention, thus ensuring the stability of the nurse team and nursing quality (46). With the continuous improvement of medical technology, higher requirements are put forward for the education level and working ability of nurses. Nurses need to constantly enrich their theoretical knowledge and improve their nursing skills in order to meet the growing nursing needs and the speed of high-quality development of hospitals. Therefore, the nurse structure should be considered and further optimized when staffing nurses.

5.1 Limitations

The study has several limitations. First of all, in order to ensure the diversity of the study subjects, we used purpose sampling to sample

the head nurses of various departments in the hospital, but the study scope was limited to one hospital, which made it difficult to obtain additional information. Secondly, the interview document data is translated from Chinese to English, and there is a certain risk of translation errors.

6 Conclusion

From the perspective of nursing managers, this study explores the related factors affecting the allocation of nurses through descriptive qualitative research, explores the specific challenges, pressures and needs of nurses in their work, and reveals the deep causes of the shortage of nurses from multiple levels and directions, rather than just stay on the quantity and statistical data. From a nursing manager's perspective, the results of this qualitative study highlight the multifaceted and interrelated factors that influence nurse staffing. Hospital-level factors are the most critical. Improving and unifying nursing personnel staffing standards is the premise of ensuring the development of high-quality nursing. Nursing managers stressed the importance of a supportive work environment, effective communication, and continuing professional development to mitigate staffing challenges. At the same time, it reveals the influence of humanistic and emotional factors, and captures the importance of humanistic care, emotional support and professional identity experienced by nurses in the work. These factors have an important impact on the job satisfaction and retention rate of nurses, thereby indirectly affecting the staffing of nurses. Addressing these factors through integrated strategies can improve nurse retention, improve the quality of patient care, and foster a more stable and satisfied nursing workforce. This study can provide deep insight and effective strategy suggestions for understanding and solving today's nurse staffing problems, so as to provide a unique contribution to the continuous development and improvement of the nursing profession.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Ethics Review Committee of Guangdong Provincial People's Hospital. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

GL: Conceptualization, Data curation, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review & editing. WW: Conceptualization, Data curation, Formal analysis, Investigation, Writing – review & editing. JP: Conceptualization, Data curation, Writing – review & editing. ZX: Supervision, Writing – review & editing. YX: Methodology, Supervision, Writing – review & editing. TS: Methodology, Project administration, Supervision, Writing – review & editing. HH: Supervision, Writing – review & editing, Funding acquisition, Resources.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Spatial effects of township health centers' health resource allocation efficiency in China

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Introduction: China is a large agricultural nation with the majority of the population residing in rural areas. The allocation of health resources in rural areas significantly affects the basic rights to life and health for rural residents. Despite the progress made by the Chinese government in improving rural healthcare, there is still room for improvement. This study aims to assess the spatial spillover effects of rural health resource allocation efficiency in China, particularly focusing on township health centers (THCs), and examine the factors influencing this efficiency to provide recommendations to optimize the allocation of health resources in rural China.

Methods: This study analyzed health resource allocation efficiency in Chinese rural areas from 2012 to 2021 by using the super-efficiency SBM model and the global Malmquist model. Additionally, the spatial auto-correlation of THC health resource allocation efficiency was verified through Moran test, and three spatial econometric models were constructed to further analyze the factors influencing efficiency.

Results: The key findings are: firstly, the average efficiency of health resource allocation in THCs was 0.676, suggesting a generally inefficient allocation of health resources over the decade. Secondly, the average Malmquist productivity index of THCs was 0.968, indicating a downward trend in efficiency with both non-scale and non-technical efficient features. Thirdly, Moran's Index analysis revealed that efficiency has a significant spatial auto-correlation and most provinces' values are located in the spatial agglomeration quadrant. Fourthly, the SDM model identified several factors that impact THC health resource allocation efficiency to varying degrees, including the efficiency of total health resource allocation, population density, PGDP, urban unemployment rate, *per capita* disposable income, *per capita* healthcare expenditure ratio, public health budget, and passenger traffic volume.

Discussion: To enhance the efficiency of THC healthcare resource allocation in China, the government should not only manage the investment of health resources to align with the actual demand for health services but also make use of the spatial spillover effect of efficiency. This involves focusing on factors such as total healthcare resource allocation efficiency, population density, etc. to effectively enhance the efficiency of health resource allocation and ensure the health of rural residents.

KEYWORDS

township health centers (THCs), resource allocation, data envelopment analysis (DEA), spatial auto-correlation, Spatial Dubin Model

1 Introduction

Being healthy is a fundamental right of individuals, and everyone possesses the opportunity and capability to attain "health equity." The allocation of health resources in rural regions significantly impacts the preservation of the most essential rights to life and health for rural inhabitants. To uphold health equity and societal stability, an increasing number of nations are prioritizing the advancement of rural healthcare services, and research on medical and healthcare in rural areas is becoming progressively comprehensive. Scholars such as Almeida have investigated the health services accessibility of rural residents through their research on 27 remote rural municipalities in Brazil (1). Additionally, Bautista Gómez and others have examined the case of Sumapas in the rural area of Bogotá, Colombia, to explore how to ensure fair access to high-quality healthcare services for rural populations (2). Meanwhile, Carey and colleagues have advocated in their research on "which primary healthcare services should be accessible to residents in rural and remote areas of Australia" that everyone should have access to primary healthcare core services at all times (3).

China has consistently prioritized rural healthcare and actively advanced rural health initiatives, while also implementing numerous practical and viable policies for public health (4, 5). From 2009 to 2011, the Chinese government invested 4.448 billion yuan for rural sanitation improvement through a 3-year health reform program (6).These measures and investments not only have the potential to enhance the health status of rural inhabitants (7) but also to stimulate economic and social progress in rural regions (8). They can also contribute to bridging the urban–rural healthcare gap (9), thereby fostering the holistic development of the healthcare sector (10). Nevertheless, many scholars perceived significant room for improvement in China's rural health development. For instance, Hu et al. argued in their study that the reimbursement policies of the New Cooperative Medical Scheme may restrict rural residents' access to healthcare services (11). Additionally, scholars like Liu have identified the substantial challenge that China faces in maintaining equity and efficiency in healthcare resource allocation and utilization amidst rapid economic growth in rural areas (12).

The township health centers (THCs) occupy a central position within China's rural three-tier medical and health service network. Serving as the crucial link between county-level medical institutions and village clinics, they play a vital role in safeguarding the health of rural residents (13). The primary responsibility of THCs is to deliver fundamental medical services, encompassing disease prevention, diagnosis, treatment, and rehabilitation (14). Alongside undertaking public health services and management functions, including planned immunization, health education, maternal and child health care, and health supervision (15). Consequently, China is actively advancing the THC construction project and continually enhancing the three-tier medical and health service system at the county, township, and village levels to safeguard the health of rural populations. Despite the government's escalating investment in THCs' basic resources following the healthcare reform, the utilization of THC medical services within the rural medical and health service system has progressively dwindled (16), with its medical service output also proved suboptimal (17). For instance, Chen et al. (18) found in their research that the efficiency of THC health resource allocation in China is low, and there are significant regional differences in health resource allocation. Xu et al. (19) asserted that there is a problem with output speed being lower than input speed in THCs in China. Furthermore, Jiang et al. (20) discovered that although the medical community can significantly increase the scale efficiency of THC expansion, they cannot effectively improve THC technical efficiency and pure technical efficiency. Moreover, numerous researchers have identified developmental challenges faced by THCs in China, including insufficient number of health personnel, shrinking service content, decreased patient satisfaction and resident trust (21, 22).

China has made remarkable progress in the development and research of rural health initiatives. For example, numerous studies have highlighted significant advancements in the construction of the rural health service system, including the establishment and coverage of county-level medical institutions, township health centers, and village clinics, for these facilities did have improved accessibility to basic medical services for rural residents (23, 24). Furthermore, many scholars have explored the training, recruitment, and incentive mechanisms to attract and retain excellent health talents to work in rural areas (25). Alongside these qualitative researches, there have been various quantitative analyses of rural health in China, contributing to a comprehensive understanding of the subject. For example, scholars such as Ao have conducted research on the equity of resource allocation in China's rural three-tier healthcare system through the Gini coefficient, health resource density index, and Theil index (26). Li et al. (27) have analyzed the effects of tiered healthcare services delivery on cost control and quality improvement in rural China using interrupted time series data. Qiu et al. (28) have explored the impact of China's healthcare system reform on improving healthcare services by evaluating the urban–rural gap in the medical system in Dalian from 2008 to 2017.

However, when examining quantitative research on the health status of rural areas in China both domestically and internationally, it becomes apparent that there is a lack of specialized research and analysis on the efficiency of health resource allocation in rural areas. Most efficiency studies conducted in rural areas are either based on cross-sectional data or are confined to the provincial level (29–31). The few efficiency studies at the national level only briefly mention the efficiency of health resource allocation without further analysis of it, such as the spatial agglomeration of efficiency and factors affecting it (12, 32).

To effectively demonstrate the efficiency of THC health resource allocation at the national level in China and conduct a more specific analysis of rural health resource allocation in China, this study fully utilized calculation software such as Microsoft Office Excel, MathWorks Matlab R2021b, and StataCorp LLC Stata16.0, and combined these with the super-efficiency SBM model and global Malmquist model to calculate the THCs' health resource allocation efficiency of 29 provinces (autonomous regions, municipalities) in China from 2012 to 2021. In addition, this study used Moran's Index to test the spatial auto-correlation and constructed spatial econometric models based on the adjacency matrix to analyze the factors that affect the efficiency of THC health resource allocation in various provinces, thereby proposing scientific references for improving the efficiency of rural health resource allocation in China.

Abbreviations: CNY, Chinese Yuan; DMU, Decision-Making Unit; DEA, Data Envelopment Analysis; EC, Technical Efficiency Change; ID, Identification; MI, Malmquist Index; SAR, Spatial Auto Regression; SDM, Spatial Dubin Model; SEM, Spatial Error Mode; TC, Technological Change; THCs, Township Health Centers; W, the rook geographical adjacency spatial weight matrix.

The innovations of this research lie in: firstly, by utilizing THCs' health resource data that can effectively represent the medical and health status in rural areas, this study achieved a national-level study on the efficiency of rural health resource allocation. Secondly, this study utilized panel data of THCs in various provinces from 2012 to 2021 to study the dynamic changes in the efficiency of THC health resource allocation. Finally, this study creatively combined spatial econometric models in the analysis of the efficiency of health resource allocation, thereby enriching the research methods of health resource allocation.

2 Materials and methods

2.1 Data source and variable selection

The spatial basic unit for this study is the provincial-level administrative regions in China from 2012 to 2021. The study chose 29 provinces, autonomous regions, and municipalities directly under the central government in China, out of the 34 provincial-level administrative regions (Due to the lack of relevant research data from Beijing, Shanghai, Hong Kong, Macao, and Taiwan, these 5 regions were excluded in our research). The specific names and numerical labels of each research region are provided in Table 1.

The calculation of the dependent variable (efficiency of THC health resource allocation) is based on the researches of scholars like Chen, Xu, Yu, etc. (17, 18, 33, 34), which includes five input variables: number of THCs, number of beds in THCs, number of practicing physicians, registered nurses, and pharmacists in THCs; Four output variables: number of diagnosed and treated patients, inpatients, discharged patients in THCs, and bed utilization rate in THCs.

The selection of influencing factors of THC health resource allocation efficiency is based on the researches of Yi, Meng, Tao, and others (35–37). These factors include 13 variables such as the efficiency of total health resource allocation, population density, and the proportion of urban population (represented by X1-X13 in the following text). The calculation methods for the efficiency of total health resource allocation and THC health resource allocation are the same, but their input and output variables differ. The input variables for the efficiency of total health resource allocation include the number of medical and health institutions, the number of health technicians, and the number of hospital beds; while the output variables include the number of diagnosed and treated patients, and the number of discharged patients. Furthermore, the calculation equation for X13 is available in Table 2. The calculation data for each single indicator and the calculation indicator of the composite variables is sourced from the latest 2013–2022 China Health Statistical Yearbook, China Health and Family Planning Statistical Yearbook, and China Statistical Yearbook. Detailed information is presented in Table 2.

2.2 Super-efficiency SBM model

Data Envelopment Analysis (DEA) serves as a widely used method for assessing efficiency, particularly in evaluating the efficiency or relative efficiency of multiple Decision-Making Units (DMUs) across various organizations such as enterprises, schools, and hospitals (38–40). DEA encompasses several models including CCR models based on constant returns to scale and BCC models based on variable returns to scale, which are commonly referred to as radial DEA models due to their proportional reduction or increase in inputs and outputs. However, the radial distance function is just one of the distance functions, other distance functions such as the farthest distance to the front, the closest distance to the strong efficient front, the closest distance to the weak efficient front, the mixed distance function, and others are also frequently employed in the DEA.

Tone first proposed the SBM model in 2001 (41), which was based on the farthest distance to the front function. This SBM model offers an advantage over traditional radial models like CCR and BCC by integrating the relaxation variable problem into inefficiency measurement (39). Furthermore, in the analysis of DEA models, it is common to have multiple DMUs identified as efficient. This poses a challenge as traditional DEA models yield maximum efficiency values of 1 for all efficient DMUs, making it difficult to distinguish further between efficient efficiencies. To solve this problem, Tone proposed the super-efficiency SBM model in 2002 (42), which has been widely used in various efficiency studies by scholars. The efficiency model for health resource allocation in this study is constructed based on the super-efficiency SBM model with variable returns to scale:

$$\rho = \min \frac{\frac{1}{m}\sum_{i=1}^{m} \overline{x_i} / x_{i0}}{\frac{1}{s}\sum_{k=1}^{s} \overline{y_k} / y_{k0}}$$

$$\text{s.t.} \begin{cases} \overline{x_i} \geq \sum_{j=1, j\neq 0}^{n} \lambda_j x_j, \forall i \\ \overline{y_k} \leq \sum_{j=1, j\neq 0}^{n} \lambda_j y_j, \forall k \\ \overline{x_i} \geq x_{i0}, y_{k0} \geq \overline{y_k} \geq 0, \lambda_j \geq 0, \sum_{j=1, j\neq 0}^{n} \lambda_j = 1, \forall i, j, k \end{cases} \quad (1)$$

This research involves the assessments of health resource allocation efficiency across 29 DMUs (x_0, y_0), with each province serving as a DMU. As shown in Eq. (1), ρ signifies the efficiency of the DMU, where the efficiency greater than or equal to 1 indicates efficient, and the efficiency less than 1 denotes inefficient. Each DMU has i types of inputs $x_i\,(i = 1,2,..,m)$, k types of outputs $y_k\,(k = 1,2,\ldots,s)$, $\overline{x_i}$ and $\overline{y_k}$ represent the average of all inputs and outputs, respectively. n represents the total number of DMUs, j represents the j-th DMU, m and s represent the total number of input and output variables, i represents the i-th input, k represents the k-th output, λ is the weight, and $\sum_{j=1, j\neq 0}^{n} \lambda_j = 1$ denotes variable returns to scale.

2.3 Global Malmquist productivity index

The Malmquist productivity index can dynamically analyze panel data from a time series perspective, which was first established and applied by Caves et al. to measure the level of productivity change (36), and can effectively integrate with DEA

10.3389/fpubh.2024.1420867

TABLE 1 Efficiency of THC health resource allocation in each province.

DMU	Regions	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Mean
1	Tianjin	1.027	1.031	0.922	1.022	1.014	1.005	0.952	1.030	1.004	1.008	1.002
2	Hebei	1.010	0.936	0.804	0.779	0.886	0.588	0.548	0.463	0.365	0.286	0.667
3	Shanxi	0.363	0.345	0.320	0.305	0.302	0.331	0.305	0.268	0.196	0.130	0.287
4	Inner Mongolia	0.332	0.350	0.325	0.299	0.324	0.332	0.297	0.212	0.179	0.156	0.281
5	Liaoning	0.473	0.465	0.440	0.418	0.426	0.464	0.430	0.357	0.244	0.208	0.392
6	Jilin	0.308	0.233	0.220	0.198	0.203	0.241	0.255	0.186	0.119	0.121	0.208
7	Heilongjiang	0.489	0.531	0.463	0.486	0.514	0.520	0.375	0.329	0.216	0.197	0.412
8	Jiangsu	0.717	0.815	0.843	0.870	0.851	1.030	0.928	1.011	0.748	0.757	0.857
9	Zhejiang	1.016	0.941	1.011	1.013	0.932	1.010	1.011	1.031	0.664	0.708	0.934
10	Anhui	0.704	0.723	0.717	0.689	0.663	0.720	0.689	0.679	0.529	0.439	0.655
11	Fujian	0.714	0.665	0.600	0.565	0.546	0.520	0.516	0.524	0.385	0.375	0.541
12	Jiangxi	1.013	0.840	0.664	0.673	0.665	0.699	0.664	0.613	0.525	0.526	0.688
13	Shandong	1.004	0.630	0.624	0.600	0.640	0.662	0.654	0.593	0.537	0.605	0.655
14	Henan	0.902	0.875	0.916	0.962	1.017	1.006	1.032	1.022	0.900	1.023	0.966
15	Hubei	0.831	0.850	0.813	0.824	0.900	1.021	1.003	1.012	0.666	0.660	0.858
16	Hunan	0.718	0.749	0.681	0.672	0.763	0.844	1.031	1.064	0.742	0.661	0.792
17	Guangdong	0.671	0.715	0.690	0.664	0.653	0.619	0.617	0.628	0.523	0.567	0.635
18	Guangxi	0.895	1.109	0.897	0.832	0.792	0.741	0.689	0.732	0.660	0.663	0.801
19	Hainan	0.883	1.007	0.909	0.809	0.735	0.686	0.550	0.466	0.178	0.161	0.638
20	Chongqing	1.022	1.011	0.923	0.881	0.891	1.009	0.940	1.032	0.885	0.917	0.951
21	Sichuan	1.052	0.955	0.896	0.872	0.918	1.047	0.950	1.046	0.801	0.786	0.932
22	Guizhou	1.101	1.005	0.762	0.614	0.552	0.582	0.632	0.648	0.512	0.550	0.696
23	Yunnan	1.016	1.029	1.011	1.011	1.015	1.015	0.982	1.013	0.842	0.872	0.981
24	Xizang	1.217	1.041	0.685	1.008	0.618	0.519	0.392	0.221	0.126	0.072	0.590
25	Shaanxi	0.423	0.407	0.401	0.420	0.392	0.432	0.426	0.379	0.240	0.232	0.375
26	Gansu	0.547	0.521	0.452	0.451	0.483	0.502	0.475	0.438	0.377	0.333	0.458
27	Qinghai	1.056	0.927	1.019	0.738	0.824	0.716	0.602	0.550	0.459	0.397	0.729
28	Ningxia	1.046	1.007	1.021	1.006	1.009	1.007	0.692	0.615	0.418	0.387	0.821
29	Xinjiang	0.749	0.865	0.927	1.008	1.005	0.949	0.765	0.822	0.544	0.344	0.798
Mean		0.804	0.778	0.723	0.713	0.708	0.718	0.669	0.655	0.503	0.488	0.676

Bold symbols represent the efficiency value greater than 1.

theory. The global Malmquist model is a Malmquist index (MI) calculation method proposed by Paster and Lovell (43). It uses the sum of each period as the reference set and has the advantage of cross-period comparability. The common reference set for each period is:

$$\left\{\left(x_j^1, y_j^1\right)\right\} \cup \left\{\left(x_j^2, y_j^2\right)\right\} \cup \ldots \cup \left\{\left(x_j^p, y_j^p\right)\right\} = S^1 \cup S^2 \cup \ldots \cup S^p = S^g \quad (2)$$

In Eq. (2), j represents the j-th DMU; S^t is the simplified form of $\left(x_j^t, y_j^t\right), t = 1, 2, \ldots, p$, and since there are 10 periods from 2012 to 2021 in this study, $p = 10$; S^g is a common reference set for each period. Therefore, in addition to the utilization of the supper-efficiency SBM model, this study further constructed the global Malmquist productivity index model:

$$M_g\left(x^{t+1}, y^{t+1}, x^t, y^t\right) = \frac{E^g\left(x^{t+1}, y^{t+1}\right)}{E^g\left(x^t, y^t\right)} \quad (3)$$

In Eq. (3), $M_g\left(x^{t+1}, y^{t+1}, x^t, y^t\right)$ is the global Malmquist productivity index, if the index is greater than 1, it indicates an increase in productivity; otherwise, it indicates a decrease in productivity. E^g represents the efficiency value of the DMU; $\left(x^t, y^t\right)$ and $\left(x^{t+1}, y^{t+1}\right)$ represent the input and output vectors of the DMU during the period_t and period_t + 1, respectively. In addition, MI can also be decomposed into technical efficiency change (EC, representing the relative relationship between actual production and production frontier) and technical change (TC, representing the change in production frontier boundary, that is the situation of technological progress), to comprehensively

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TABLE 2 Statistical description of variables included in the analysis of this study.

Category	Variables	Mean	Std. dev.	Minimum	Maximum
Inputs	Number of THCs (units)	1256.74	780.51	133.00	4606.00
	Number of beds in THCs (units)	43540.16	32816.33	2573.00	135705.00
	Number of practicing physicians in THCs (persons)	16136.09	11703.86	559.00	45053.00
	Number of registered nurses in THCs (persons)	11525.91	8965.37	160.00	33728.00
	Number of pharmacists in THCs (persons)	2629.65	1985.91	61.00	7919.00
Outputs	Number of diagnosed and treated patients in THCs (person-times)	37200000.00	30600000.00	2522889.00	126000000.00
	Number of inpatients in THCs (person-times)	1296595.00	1180334.00	8372.00	4895237.00
	Number of discharged patients in THCs (person-times)	1292245.00	1175469.00	8297.00	4875351.00
	Bed utilization rate in THCs (%)	51.32	15.59	9.60	81.10
Dependent variable	(Y) efficiency of THC health resource allocation	0.68	0.27	0.07	1.22
Independent variables (Influencing factors)	(X1) Efficiency of total health resource allocation	0.67	0.19	0.25	1.20
	(X2) Population density (persons/km^2)	309.44	264.59	2.56	1209.15
	(X3) The proportion of urban population (%)	74.51	292.90	22.87	5042.00
	(X4) Dependency ratio (%)	39.30	6.83	24.98	57.79
	(X5) The proportion of illiterate population (%)	5.99	6.32	1.01	41.18
	(X6) PGDP (CNY)	54919.96	22568.86	5896.00	137039.00
	(X7) Registered urban unemployment rate (%)	3.24	0.56	1.80	4.60
	(X8) Healthcare consumer price index (last year = 100)	102.67	2.43	99.30	115.40
	(X9) *Per capita* disposable income (CNY)	23800.33	7804.61	9746.80	57540.50
	(X10) *Per capita* healthcare expenditure ratio (%)	8.20	2.07	2.63	13.57
	(X11) Public budget expenditures for healthcare (CNY)	1057.44	489.26	391.37	3944.54
	(X12) Passenger traffic volume (10,000 persons)	61846.29	58028.25	825.00	574265.90
	(X13) Elderly population coefficient (%)	10.81	2.75	4.98	18.80

The elderly population coefficient is calculated by dividing the population aged 60 and above by the total population, and then multiplying by 100%.

reflect the productivity change of a DMU from period_t to period_t + 1. The specific formula is shown in Eq. (4):

$$M_g\left(x^{t+1},y^{t+1},x^t,y^t\right)=\frac{E^g\left(x^{t+1},y^{t+1}\right)}{E^g\left(x^t,y^t\right)}$$
$$=\frac{E^{t+1}\left(x^{t+1},y^{t+1}\right)}{E^t\left(x^t,y^t\right)}\left(\frac{E^g\left(x^{t+1},y^{t+1}\right)}{E^{t+1}\left(x^{t+1},y^{t+1}\right)}\cdot\frac{E^t\left(x^t,y^t\right)}{E^g\left(x^t,y^t\right)}\right)=EC\times TC_g \quad (4)$$

2.4 Spatial auto-correlation

The spatial weight matrix illustrates the level of interdependence among geographical or economic attribute values of spatial section units, serving as a crucial connection between the spatial econometric model in theoretical analysis and the actual spatial effects in the real world (44). Therefore, the choice of spatial econometric model must be based on the suitable spatial weight matrix. Due to the limitations of the national health plan in allocating medical and health resources, and the common use of adjacency spatial weight matrices in spatial studies to demonstrate the mutual influence between neighboring provinces, this article utilizes the Rook geographical adjacency spatial weight matrix as the weight matrix. To prevent missing values in the spatial weight matrix, Hainan is considered adjacent to Guangdong Province due to its geographical proximity and close connection. The specific form is as follows:

$$w_{ij}=\begin{cases}1 \text{ when i is adjacent to j}\\ 0 \text{ when i is not adjacent to j or i = j}\end{cases} \quad (5)$$

In Eq. (5), w_{ij} represents the spatial weight matrix between province_i and province_j. There are two forms of spatial auto-correlation: global and local. Global spatial auto-correlation can test the overall spatial distribution pattern of THC health resource allocation efficiency in 29 provinces of China and reflect spatial dependence; local spatial auto-correlation can specifically reflect the degree of spatial correlation between efficiency values in each province and neighboring regions, and identify the contribution of efficiency observations in each spatial unit. The most commonly used global spatial auto-correlation test is the Moran's Index:

$$\text{Moran's Index}=\frac{\sum_{i=1}^{n}\sum_{j=1}^{n}w_{ij}\left(x_i-\bar{x}\right)\left(y_i-\bar{y}\right)}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n}w_{ij}} \quad (6)$$

In Eq. (6), $S^2=\frac{\sum_{i=1}^{n}\left(x_i-\bar{x}\right)}{n}$ represents sample variance; n represents the number of provinces, x_i, y_i represents the efficiency of health resource allocation in province-level THCs, $\bar{x}$, $\bar{y}$ represent the average efficiency; w_{ij} represents (i,j) element in the spatial weight matrix, and $\sum_{i=1}^{n}\sum_{j=1}^{n}w_{ij}$ represents the combination of all spatial weight matrices. The value range of Moran's Index is generally between −1 and 1. When Moran's Index >0, it indicates a positive spatial auto-correlation. The larger the value, the more pronounced the spatial auto-correlation. When Moran's Index <0, the spatial auto-correlation is negative. The smaller the value, the greater the spatial difference. When Moran's Index = 0, the space presents randomness. Furthermore, the Moran scatter diagram is used to reflect the characteristics of local spatial agglomeration, the four quadrants of the Moran scatter diagram are used to identify the relationship between a region and its neighbors. The first and third quadrants represent positive spatial auto-correlation, indicating a similar value agglomeration feature; the second and fourth quadrants represent negative spatial auto-correlation, indicating an opposite value agglomeration feature.

2.5 Spatial econometric model

The spatial econometric model addresses the deficiency of traditional econometric models in accounting for spatial correlation arising from geographical distance. It not only assesses the direct impact of influencing factors within a particular region but also evaluates the spillover effect on adjacent regions, that is, the influences of dependent variable and independent variables from other regions on the local dependent variable. The model is expressed as follows:

$$Y_{it}=\rho w_i Y_t+\beta X_{it}+\theta D_i X_t+\mu_i+\gamma_t+\varepsilon_{it},\varepsilon_{it}=\lambda w_i\varepsilon_t+\nu_{it} \quad (7)$$

In Eq. (7), Y_{it} represents the efficiency of health resource allocation in province-level THCs, X_{it} is an N*N order explanatory (exogenous) variable matrix, and w_i is the i-th row of the N*N order spatial weight matrix; $\theta D_i X_t$ represents the spatial Weight lag term of the independent variable, ρ is the spatial auto-regressive coefficient, β is the regression coefficient of the independent variable, θ is the spatial regression coefficient of the independent variable, λ is the spatial error regression coefficient, μ_i represents individual effect, γ_t is the time effect, ν_{it} is a random interference term that follows independent identical distribution, i represents province, and t represents year.

If $\lambda=0$ and $\theta=0$, the spatial econometric model becomes the Spatial Auto-Regression model (SAR), which demonstrates the influence of THC health resource allocation efficiency in other provinces and independent variables on the efficiency of local regions; If $\rho=0$ and $\theta=0$, it transforms into the Spatial Error Model (SEM), which shows the influence of spatial interference variables and independent variables on the local THC health resource allocation efficiency, excluding spatial independent variables; If $\theta=0$, it represents the spatial auto-correlation model, which encompasses the spatial lag model and the spatial error model; If $\lambda=0$, it becomes the Spatial Dubin Model (SDM), simultaneously considering the direct influence of dependent variables and the spatial lag influence of them, both with the influence of THC health resource allocation efficiency in other provinces on the efficiency of local region. In order to better demonstrate the selection criteria for the model, this study created a flowchart based on the research of scholars such as Chen, as shown in Figure 1.

3 Results

3.1 Efficiency calculation results

This study calculated the THCs' health resource allocation efficiency values of 29 provinces (autonomous regions, municipalities)

in China from 2012 to 2021 by using Matlab R2021b software and a super-efficiency SBM model based on variable returns to scale. The specific results are shown in Table 1.

The research findings indicate that the mean efficiency of THC health resource allocation in 29 Chinese provinces from 2012 to 2021 is 0.676, which shows the efficiency of THC health resource allocation in various regions generally exhibits DEA inefficiency with overall low efficiency. From a dynamic perspective, the overall THCs' health resource allocation efficiency in China has displayed a declining trend over the past decade (Figure 2), with the average efficiency dropping from 0.804 in 2012 to 0.488 in 2021. Among them, the mean efficiency reduction between 2019 and 2020 was the largest, which this study speculated may be related to COVID-19.

Specifically, 19 provinces in China, such as Tianjin (8 years), Yunnan (7 years), Zhejiang (6 years), Henan (5 years), Chongqing (4 years), Hubei (3 years), Jiangsu (2 years), Hebei (1 year), etc., have been at the technological forefront in terms of THCs' health resource allocation efficiency in some years. The remaining 10 provinces have not been at the technological forefront once during this decade. Moreover, there is a notable disparity in the efficiency of THC health resource allocation among different regions in China: only Tianjin Province has an average efficiency greater than 1, 9 regions such as Yunnan and Henan have an average efficiency between 0.8 and 1, and 10 regions such as Xinjiang and Hunan have an average efficiency between 0.6 and 0.8. The average efficiency values of the other 9 provinces are all below 0.6, indicating that there is a notable disparity in the average efficiency values among different provinces. This fact is also reflected in the comparison of the top and bottom three regions in terms of average efficiency. The top three regions are Tianjin (1.002), Yunnan (0.981), and Henan (0.966), while the bottom three regions are Jilin (0.208), Inner Mongolia (0.281), and Shanxi (0.287), demonstrating a significant difference in average efficiency values.

3.2 Productivity changes

This study also combined the super-efficiency SBM model with the global Malmquist model to calculate the Malmquist index (MI) of THCs' health resource allocation efficiency and its decomposition indicators in 29 provincial administrative regions of China from 2012 to 2021. Then, dynamic analysis and evaluation were conducted separately. The specific results are shown in Figure 3.

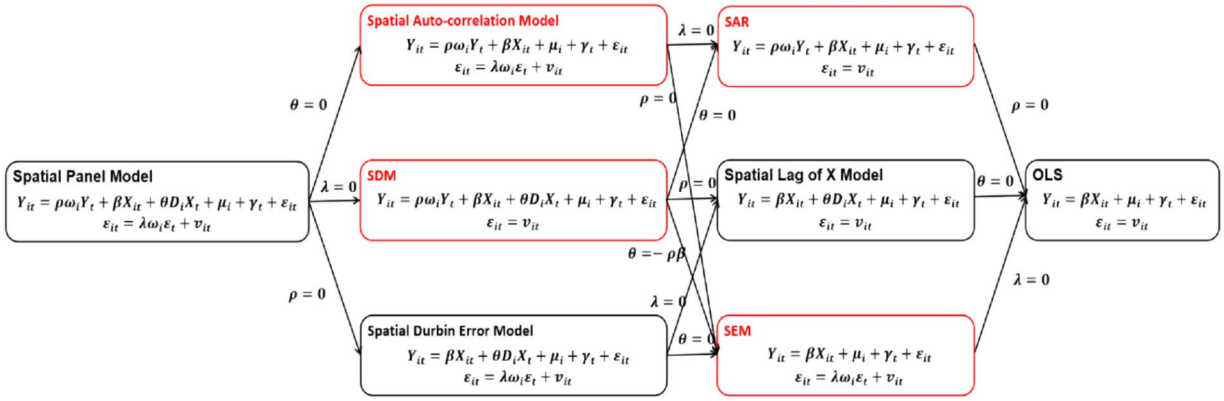


FIGURE 1
Model selection criteria flowchart. This figure is based on the book *"Advanced Econometrics and Stata Applications"* by Chinese scholar Chen Qiang. The models indicated by the red border in the figure is the spatial econometric models mentioned in the main text.

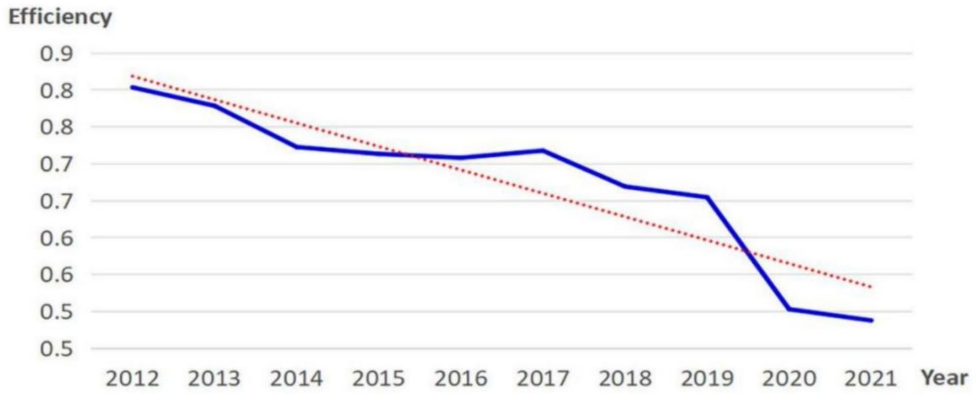


FIGURE 2
Changes in efficiency of THC health resource allocation nationwide.

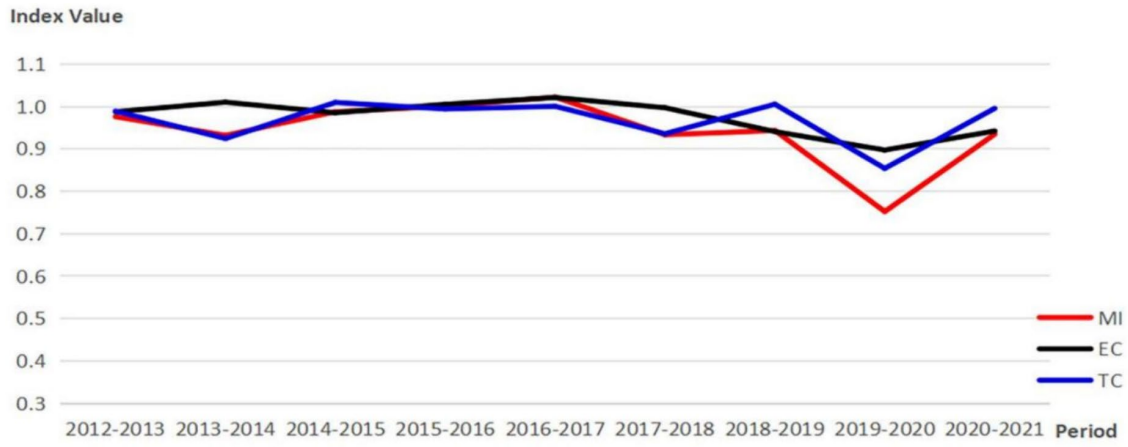


FIGURE 3
Changes and decomposition of the Malmquist Index.

According to Figure 3, the Malmquist Index (MI) of THCs' health resource allocation efficiency in China has remained around 1 from 2012 to 2021, indicating relatively stable global Malmquist productivity of THCs in China over the past decade. During the period of sudden decline in MI from 2019 to 2020, MI was 75.2%, EC was 89.7%, and TC was 85.4%, suggesting that the decrease in global Malmquist productivity of THCs in China during the COVID-19 period is likely limited by both technology level and scale efficiency. At the provincial level, the average MI, EC, and TC of THCs' health resource allocation efficiency in 29 provinces in China are 0.942, 0.976, and 0.968, this indicates that the productivity of THCs in China has been declining over the past decade. Details are illustrated in Table 3.

3.3 Spatial correlation test

3.3.1 Global spatial auto-correlation

Based on Table 4, it is evident that despite the fluctuations in Moran's index of THCs' health resource allocation efficiency, it remains consistently positive (with an average of 0.238). Except for 2016 and 2017, Moran's index has surpassed the 10% significance level test over the past 8 years. These suggest that the spatial distribution of THCs' health resource allocation efficiency across 29 provinces in China exhibits significant positive spatial auto-correlation characteristics over the last decade, with relatively stable spatial dependence.

3.3.2 Local spatial auto-correlation

To examine the spatial correlation of a specific region, this study presents a Moran scatter diagram of THCs' health resource allocation efficiency. As shown in Figure 4, only 2012, 2015, 2018, and 2021 are selected as representative years, where each scatter represents a DMU.

The Moran scatter diagram categorizes the THCs' health resource allocation efficiency clusters of 29 provinces into four quadrants: The first quadrant (High-High) indicates that the high-efficiency province is surrounded by other regions that are also high-efficiency; The second quadrant (Low-High) indicates that the low-efficiency province is surrounded by other regions with high-efficiency; The third quadrant (Low-Low) indicates that the low-efficiency province is surrounded by other regions that are also low-efficiency; The fourth quadrant (High-Low) indicates that the high-efficiency province is surrounded by other regions with low-efficiency. The first and third quadrants show positive spatial auto-correlation, while the second and fourth quadrants show negative spatial auto-correlation. The scatter diagram results show that most regions were located in the first quadrant (High-High) and third quadrant (Low-Low), indicating a significant positive spatial auto-correlation in the efficiency of THC health resource allocation, which is consistent with the global test results. Overall, the Moran scatter points of THCs' health resource allocation efficiency in various provinces were 55.17, 55.17, 51.72, and 65.52% of the total sample in 2012, 2015, 2018, and 2021 year, respectively (see Table 5).

3.4 Optimal model selection

3.4.1 LM test

This study first made a preliminary judgment on the model selection through the widely used LM test in spatial econometric research. Both robust tests of Spatial Error and Spatial lag, displayed in Table 6, rejected the null hypothesis at a significance level of 1%, indicating that the selected sample has a dual effect of spatial lag and spatial error. Therefore, it is determined that SEM and SAR models are meaningful in this study and all SDM, SEM, and SAR models can be utilized in this study.

3.4.2 Degradation test

As shown in Table 7, this study conducted a degradation test on the SDM model through the combination of LR and Wald tests, and the results showed that the SDM model did not degrade into either SAR or SEM models. In addition, the Hausman test results indicated that a fixed effects model should be used; the LR test results also showed that a time and individual dual fixed effects model should be selected. Consequently, so this study selected the SDM model with

TABLE 3 MI and its decomposition by province.

DMU	Regions	MI	EC	TC
1	Tianjin	1.000	1.009	0.992
2	Hebei	0.878	0.914	0.991
3	Shanxi	0.901	0.958	0.944
4	Inner Mongolia	0.926	0.985	0.944
5	Liaoning	0.920	0.969	0.950
6	Jilin	0.918	0.972	0.944
7	Heilongjiang	0.916	0.971	0.942
8	Jiangsu	1.015	1.004	1.010
9	Zhejiang	0.971	1.003	0.967
10	Anhui	0.953	0.961	0.994
11	Fujian	0.935	0.968	0.965
12	Jiangxi	0.934	0.962	0.988
13	Shandong	0.956	0.969	1.000
14	Henan	1.016	1.007	1.010
15	Hubei	0.984	0.998	0.984
16	Hunan	1.002	1.002	1.001
17	Guangdong	0.984	0.976	1.013
18	Guangxi	0.973	0.999	0.972
19	Hainan	0.857	0.892	0.964
20	Chongqing	0.992	1.031	0.963
21	Sichuan	0.974	0.991	0.982
22	Guizhou	0.934	0.942	0.995
23	Yunnan	0.985	1.000	0.985
24	Xizang	0.767	0.898	0.854
25	Shaanxi	0.945	0.982	0.962
26	Gansu	0.949	0.988	0.961
27	Qinghai	0.905	1.009	0.894
28	Ningxia	0.905	1.001	0.904
29	Xinjiang	0.937	0.955	0.988
Mean		0.942	0.976	0.968

Bold symbols represent values greater than 1.

time and individual dual fixed effects as the optimal spatial econometric model for this study.

3.5 Regression results and spatial effect decomposition

This research utilized Stata software and three spatial econometric models, SDM, SEM, and SAR, to perform spatial regression on the THCs' health resource allocation efficiency across 29 provinces in China. The findings are presented in Table 8. The regression results revealed that the SDM model exhibited the lowest σ^2 and the highest goodness of fit R^2, making it the optimal model with the highest goodness of fit among the three models. The spatial auto-regression coefficients of three models were all negative and significant, indicating a substantial spatial negative auto-correlation in the

TABLE 4 Global Moran index.

Year	Moran's index	Z	*p*-value
2012	0.360***	3.202	0.001
2013	0.376***	3.345	0.001
2014	0.238**	2.217	0.027
2015	0.258**	2.377	0.018
2016	0.135	1.379	0.168
2017	0.126	1.298	0.194
2018	0.258**	2.363	0.018
2019	0.241**	2.220	0.026
2020	0.203*	1.930	0.054
2021	0.186*	1.789	0.074

*p-value < 0.1, **p-value < 0.05, ***p-value < 0.01.

efficiency of THC health resource allocation in China. This implies that the change in the efficiency of THC health resource allocation in a province will cause a change in the efficiency of THC health resource allocation in its neighboring provinces, and this change generally shows an inhibitory effect. Moreover, the regression results of the optimal model SDM indicated that factors such as the efficiency of total health resource allocation, population density, PGDP, urban unemployment rate, *per capita* disposable income, *per capita* healthcare expenditure ratio, public budget expenditures for healthcare, and passenger traffic volume all have varying degrees of impact on the efficiency of THC health resource allocation.

Although SDM explains the economic spatial correlation between provinces, the estimation results cannot directly reflect the direct effects and indirect effects due to the inclusion of spatial lag effects between dependent and independent variables in SDM. Therefore, it is necessary to calculate the partial calculus of SDM and decompose the direct and indirect effects of independent variables (45). The direct effect describes the direct impact of the independent variables on the efficiency in local or neighboring provinces; The indirect effect shows the indirect impact of the independent variables on efficiency within a province through neighboring provinces. The specific effect decomposition results are shown in Table 9.

4 Discussion

4.1 Coexistence of inefficiencies and differences

The research findings showed a continuous decline in the average efficiency of THC health resource allocation in China from 2012 to 2021, dropping from 0.804 in 2012 to 0.488 in 2021. This study suggests that this decline may be attributed to three factors. Firstly, it may be associated with the disorderly expansion of urban large hospitals in China over the past decade. According to the data displayed in the China Health Statistical Yearbook, the growth rate of the total number of beds in overall medical institutions is much higher than that of township health centers (46). Furthermore, scholarly evidence suggests that the expansion of urban large hospitals has resulted in an influx of rural patients (47), thereby reducing the proportion of patients in township health centers and diminishing rural efficiency.

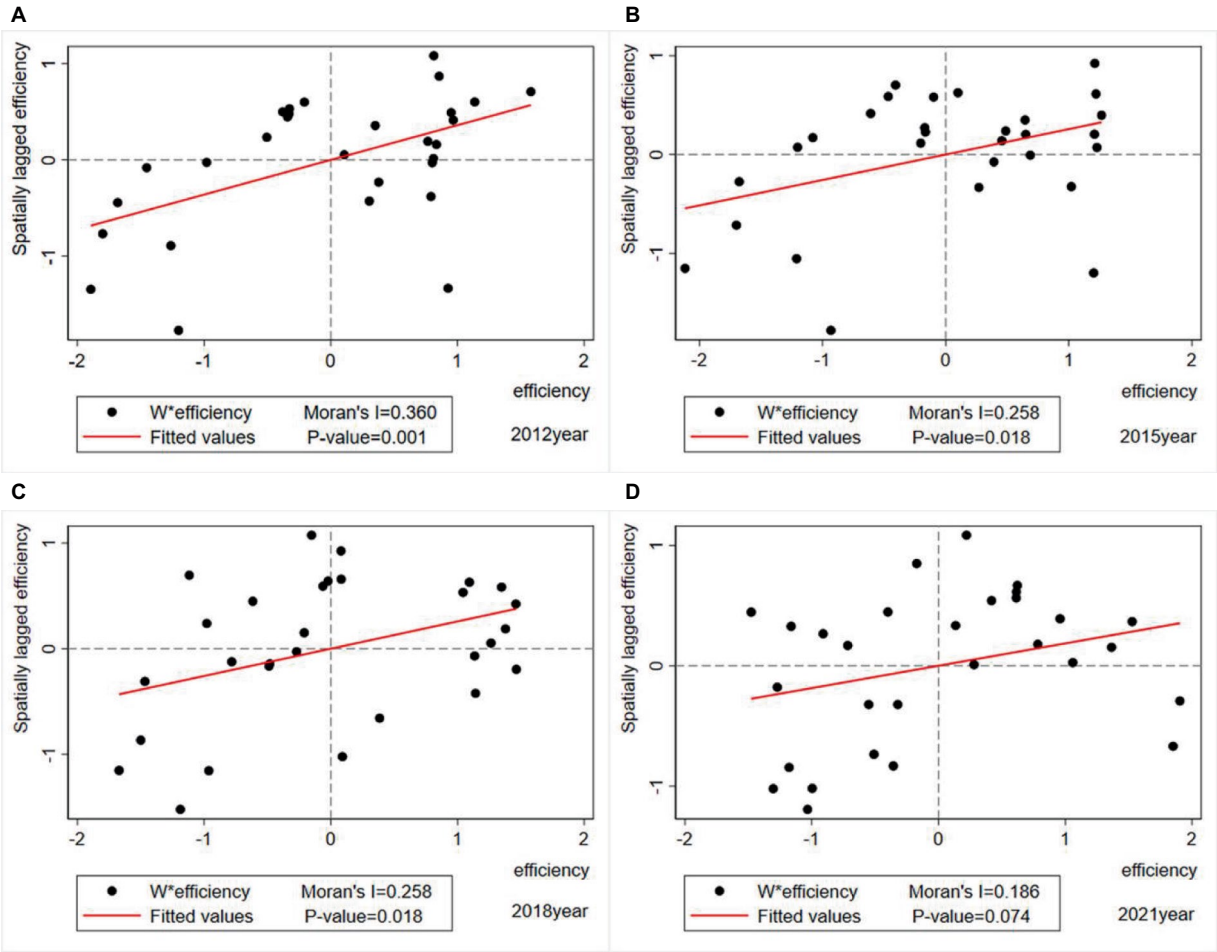


FIGURE 4
Moran scatter diagram of THCs' health resource allocation efficiency. **(A)** 2012 Moran scatter diagram. **(B)** 2015 Moran scatter diagram. **(C)** 2018 Moran scatter diagram. **(D)** 2021 Moran scatter diagram.

Secondly, this may be related to the overall increase in the urbanization rate. With the unrelenting improvement of the urbanization rate in China (48, 49), the development of various conditions in urban areas, including medical and healthcare, surpass those in rural areas. In addition, the current living conditions of people are getting better and the *per capita* disposable income is constantly increasing (50). As a result, more and more residents are inclined to seek medical treatment at large urban hospitals with more advanced medical and health technologies when they are sick, resulting in the shrinkage of THCs' healthcare services.

Thirdly, such results may indeed demonstrate the fact that there is room for improvement in the efficiency of THC health resource allocation in rural areas of China. That is, the current hierarchical diagnosis and treatment system in China is not perfect, and an orderly medical pattern has not yet been formed. Nowadays, many large tertiary hospitals in cities have utilized medical and health resources that should have been used to diagnose and treat common diseases in grassroots medical institutions, resulting in unclear division of labor and low efficiency among institutions. Many studies have also indicated that there is indeed a problem of low efficiency in the allocation of rural health resources in China. For example, scholars such as Feng and Liu have concluded in their studies that the overall efficiency level of rural public health resource allocation in China is relatively low (31, 51). Chen and others have also written a research paper specifically on how to improve the uneven distribution of medical resources between urban and rural areas in China (52).

The research results also show that over one-third of the provinces in China have never reached the technological forefront in terms of THCs' health resource allocation efficiency during the past decade, and there are also 9 provinces with average efficiencies below 0.6 over the past decade. These indicate that many regions in China's 29 provinces have been in a relatively inefficient state of THCs' health resource allocation efficiency for a long time. In addition, this study has also identified significant disparities in the efficiency of THC health resource allocation across different provinces in China. For instance, over the last decade, Tianjin province has displayed the highest efficiency in THCs' health resource allocation, averaging 1.002, whereas Jilin province has exhibited the lowest efficiency, with an average of only 0.208. The disparity in THCs' health resource allocation efficiency between these two provinces is nearly fivefold, indicating a significant difference in resource allocation among provinces, which may be related to the local economic and social development levels. What's more, this study suggests focusing on the input aspects such as the number of beds, physicians, registered nurses, and

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TABLE 5 Cluster test for the efficiency of THC health resource allocation.

Year	Spatial aggregation		Spatial discretization	
	High-High (I)	Low-Low (III)	Low-High (II)	High-Low (IV)
2012	Tianjin, Shandong, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Xizang, Qinghai (9)	Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shaanxi, Gansu (7)	Jiangsu, Anhui, Fujian, Hunan, Guangdong, Xinjiang (6)	Hebei, Zhejiang, Jiangxi, Henan, Hubei, Hainan, Ningxia (7)
2015	Tianjin, Jiangsu, Hubei, Guangxi, Sichuan, Yunnan, Xizang, Qinghai, Xinjiang (9)	Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Guangdong, Shaanxi (7)	Anhui, Fujian, Jiangxi, Shandong, Hunan, Guizhou, Gansu (7)	Hebei, Zhejiang, Henan, Hainan, Chongqing, Ningxia (6)
2018	Jiangsu, Zhejiang, Anhui, Hubei, Hunan, Guangxi, Chongqing (7)	Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Gansu, Qinghai (8)	Fujian, Jiangxi, Shandong, Guangdong, Guizhou, Xizang, Shaanxi (7)	Tianjin, Henan, Hainan, Sichuan, Yunnan, Ningxia, Xinjiang (7)
2021	Jiangsu, Zhejiang, Jiangxi, Shandong, Hubei, Hunan, Guangxi, Chongqing, Guizhou, Yunnan (10)	Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Gansu, Qinghai, Ningxia, Xinjiang (9)	Hebei, Anhui, Fujian, Hainan, Xizang, Shaanxi (6)	Tianjin, Henan, Guangdong, Sichuan (4)

Arabic numerals in parentheses represent the number of provinces, cities, and districts.

pharmaceuticals in THCs, and the output aspects such as the number of diagnosed and treated patients, inpatients, discharged patients, and bed utilization rate in THCs can enhance the overall efficiency of THC health resource allocation in China.

4.2 The overall decline in productivity

The research findings indicate that over the period from 2012 to 2021, only four provinces in China (Tianjin, Jiangsu, Henan, and Hunan) exhibited average MI values equal to or greater than 1 out of the 29 provinces. The efficiency growth in Jiangsu, Henan, and Hunan provinces is found to be influenced comprehensively by scale efficiency and technological progress, while the primary factor affecting the efficiency growth in Tianjin is the improvement of scale efficiency. The remaining 25 provinces experienced a global Malmquist productivity of less than 1 over these 10 years, suggesting a declining trend in the efficiency of THC health resource allocation in the majority of Chinese provinces during the sample period. Provinces with average MI values below 1, such as Zhejiang, Chongqing, Yunnan, Qinghai, and Ningxia, are primarily impacted by technological decline. Shandong and Guangdong provinces are mainly affected by the decline in scale efficiency. Eighteen provinces, including Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Anhui, Fujian, Jiangxi, Hubei, Guangxi, Hainan, Sichuan, Guichou, Xizang, Shanxi, Gansu, and Xinjiang, have been affected by both technological decline and a decline in scale efficiency. Furthermore, in terms of MI ranking, Henan (1.016), Jiangsu (1.015), and Hunan (1.002) are the top three, while Xizang (0.767), Hainan (0.857), and Hebei (0.878) are the bottom three. These results not only indicate that the efficiency of THC health resource allocation in some provinces is somewhat constrained but also suggest that there is a certain gap in the productivity of THCs among provinces.

The overall productivity of THCs in various provinces of China is declining, as the average Malmquist index of 29 provinces is 0.942 over the past decade, indicating an average decrease of 3.2% in THCs' productivity nationwide. Moreover, the decomposition index EC of MI is 0.976 and TC is 0.968, indicating the declining efficiency of THC health resource allocation in China is due to its change in productivity being both "non-scale efficient" and "non-technical efficient," which results in the problem of insufficient investment scale and inefficiency coexisting in the allocation of THCs' health resources.

Therefore, this study suggests that THCs can not only improve the efficiency of health resource allocation in rural areas from the perspective of input–output but also enhance it through technological progress and scientific management (53). In terms of technological progress, each THC should focus on enhancing its technological capabilities, which can be achieved through scientific methods such as strengthening its treatment technology advantages, improving disease prevention and control technologies, promoting rehabilitation technological efficacy, and completely improving the utilization efficiency of health resources. In the complex situation of low efficiency coexists with both redundant and insufficient in investment (54), government departments need to carefully consider the efficiency of resource allocation in reality, and allocate high-quality health resources reasonably according to needs. For example, when providing health financial funding to THCs in various provinces, the focus of investment should be adjusted to improve resource utilization efficiency, avoiding blind expansion and redundancy of health resource investment scale (55).

4.3 Spatial auto-correlation and agglomeration

From a global spatial auto-correlation perspective, despite fluctuations in Moran's index of THCs' health resource allocation efficiency in China between 2012 and 2021, all values remained positive (with a mean of 0.238). Moreover, 80% of the Moran's index values over the past decade passed the significance test. This implies there is a significant positive spatial auto-correlation in the THCs' health resource allocation efficiency across the 29 provinces in China, with relatively stable spatial dependence. This spatial interdependence

TABLE 6 LM test.

Test		Statistic	Degree of freedom	*p*-value
Spatial error	Lagrange multiplier	1.675	1.00	0.196
	Robust Lagrange multiplier	7.409	1.00	0.006
Spatial lag	Lagrange multiplier	5.301	1.00	0.021
	Robust Lagrange multiplier	11.035	1.00	0.001

TABLE 7 LR, Wald, and Hausman tests.

Test		$\chi 2$	Degree of freedom	*p*-value
LR test	Individual fixed	37.180	24	0.042
	Time fixed	304.790	24	0.000
	Degradation test for SAR	58.140	13	0.000
	Degradation test for SEM	55.730	13	0.000
Wald test	Degradation test for SAR	63.87	11	0.000
	Degradation test for SEM	61.94	13	0.000
Hausman test		45.190	10	0.000

is also evident in the regression analysis of efficiency. The negative spatial auto-regressive coefficients in three selected spatial econometric models (SDM, SAR, and SEM) all rejected the null hypothesis at a 10% significance level. This suggests that the changes in THCs' health resource allocation efficiency in one province will impact neighboring provinces and exert inhibitory effects overall.

Furthermore, through local spatial auto-correlation tests like the Moran scatter diagram and cluster tests, this research illustrates the specific spatial clustering of THCs' health resource allocation efficiency in various Chinese provinces more accurately. These findings revealed the spatial agglomerations of THCs' health resource allocation efficiency in China's provinces with an increasing positive spatial auto-correlation trend over these years. However, there are specific differences in the spatial aggregation and spatial discretization quadrant of each province. For example, in the quadrant of spatial aggregation, Guangxi Province has remained stable in the first quadrant (High-High) over these 4 years, indicating that the THCs' health resource allocation efficiency of Guangxi Province is efficient and surrounded by other provinces that are also efficient; Shanxi, Inner Mongolia, Liaoning, Jilin, and Heilongjiang province are stably in the third quadrant (Low-Low), indicating that the THCs' health resource allocation efficiency in these regions is inefficient and surrounded by other provinces that are also inefficient. In the quadrant of spatial discretization, Fujian Province has remained stable in the second quadrant (Low-High) for these 4 years, indicating that the THCs' health resource allocation efficiency of Fujian Province is low, but it is surrounded by other provinces with high efficiency; Henan Province remains steady in the fourth quadrant (High-Low), indicating that the THCs' health resource allocation efficiency of the Henan Province is high, but it is surrounded by other provinces with low efficiency.

To promote the balanced development of rural healthcare in China, strategies like enhancing inter-provincial communication (56) and establishing a holistic health service data management system can be implemented to create a network framework that spans horizontally, vertically, and to the peripheries (57). This approach aims to mitigate resource disparities among regions and foster a collaborative health resource mechanism with neighboring areas through the efficient allocation of health resources (58).

4.4 Multivariate influencing factors and spatial spillover effects

The regression findings from the optimal spatial econometric model SDM in this research indicate that there is a significant negative spatial auto-correlation in China's THCs' health resource allocation efficiency. The spatial auto-regression coefficient for THCs' health resource allocation efficiency in China from 2012 to 2021 is $\rho = -0.1555403$, passing the significance test at 10%. This implies that the efficiency of THC health resource allocation in one province can impact the efficiency of surrounding areas. Therefore, provinces aiming to enhance their health resource allocation efficiency should fully consider the spatial spillover effects from neighboring high-efficiency regions to maximize the spatial impact on THCs' health resource allocation efficiency and enhance the overall national health resource allocation efficiency.

The explanatory mechanism of this study is to select representative indicators from multiple perspectives such as society, economy, culture, and education to study the influencing factors of the efficiency of health resource allocation in THCs. Under this mechanism, we selected 13 influencing factors based on the extensive spatial econometric research literature conducted by scholars such as Yi, Meng, Tao, and others in the field of health resource allocation. From the results of the regression, the coefficients of the efficiency of total health resource allocation and PGDP are positive and both reject the null hypothesis at a significance level of 1%. This means that the higher the efficiency of total health resource allocation and PGDP, the higher the efficiency of THC health resource allocation in the local province. The coefficients of public budget expenditures for healthcare and passenger traffic volume are negative and significant, indicating that these influencing factors will have an inhibitory effect on the improvement of THCs' health resource allocation efficiency in the local province. The spatial lag coefficient of the *per capita* healthcare expenditure ratio is positive and rejects the null hypothesis at a significance level of 1%, indicating that the higher the healthcare expenditure ratio in neighboring provinces, the higher the efficiency of THC health resource allocation in the local province. The coefficient of population density is negative and significant, while the coefficient of the spatial lag term is significantly positive. This indicates that the improvement of population density in a province will have an inhibitory effect on the efficiency of THC health resource allocation itself, and have a significant promoting effect on the efficiency of THC health resource allocation in neighboring provinces. The coefficient and spatial lag coefficient of the registered urban unemployment rate are both negative and through hypothesis testing

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TABLE 8 Regression results of spatial econometric models.

Variable	SDM		SAR		SEM	
	Coefficient	*p*-value	Coefficient	*p*-value	Coefficient	*P*-value
X1	0.439881 3***	0.000	0.318698 2***	0.000	0.314158 3***	0.000
X2	−0.001976 7**	0.012	−0.002147 5***	0.006	−0.001984 3**	0.011
X3	0.000018 4	0.285	0.000029 2	0.111	0.000025 8	0.157
X4	0.004530 4	0.221	0.007096 1*	0.071	0.006546 0*	0.086
X5	−0.003603 2	0.533	−0.010137 1*	0.092	−0.008927 2	0.125
X6	0.000002 6***	0.005	0.000002 8***	0.003	0.000003 2***	0.001
X7	−0.043971 7***	0.007	−0.021269 8	0.186	−0.033289 2**	0.048
X8	0.001025 1	0.722	−0.000735 6	0.806	−0.001072 6	0.712
X9	0.000017 9***	0.001	0.000011 6**	0.010	0.000007 3	0.124
X10	0.009840 7	0.279	0.017688 8*	0.053	0.021400 9**	0.022
X11	−0.000330 5***	0.000	−0.000321 8***	0.000	−0.000308 4***	0.000
X12	−0.000000 3*	0.071	−0.000000 4**	0.033	−0.000000 4**	0.044
X13	0.015681 3	0.151	0.000253 4	0.981	0.001004 4	0.922
W*X1	−0.026378 2	0.854	–	–	–	–
W*X2	0.004133 2**	0.015	–	–	–	–
W*X3	−0.000049 8	0.279	–	–	–	–
W*X4	0.001228 0	0.873	–	–	–	–
W*X5	0.008916 8	0.488	–	–	–	–
W*X6	0.000002 5	0.199	–	–	–	–
W*X7	−0.226241 0***	0.000	–	–	–	–
W*X8	0.005591 5	0.367	–	–	–	–
W*X9	−0.000048 9***	0.000	–	–	–	–
W*X10	0.055752 5***	0.007	–	–	–	–
W*X11	0.000041 0	0.639	–	–	–	–
W*X12	0.000000 1	0.768	–	–	–	–
W*X13	0.025130 9	0.248	–	–	–	–
ρ/λ	−0.155540 3*	0.084	−0.154292 9**	0.045	−0.252842 0**	0.010
σ^2	0.005787 5***	0.000	0.007064 0***	0.000	0.006945 8***	0.000
R^2	0.414		0.162		0.213	

*p-value < 0.1, **p-value < 0.05, ***p-value < 0.01.

at a significance level of 1%, it is shown that the urban unemployment rate has a significant spatial inhibitory effect and effectively controls the unemployment rate will promote the efficiency of THC health resource allocation in both local province and neighboring provinces. The coefficient of *per capita* disposable income is positive while the coefficient of its spatial lag term is negative, and both coefficients reject the null hypothesis at a significance level of 1%. This indicates that the improvement of disposable income in a province will not only promote the efficiency of THC health resource allocation itself but also have a significant inhibitory effect on the improvement of THCs' health resource allocation efficiency in neighboring provinces.

In addition, this study also decomposed the spatial effects of various influencing factors on the efficiency of THC health resource allocation. From a direct effect perspective, for every 1% increase in the efficiency of total health resource allocation, PGDP, and *per capita* disposable income, the THCs' health resource allocation efficiency in local province increases by 44.3793, 0.0003, and 0.0020%, respectively. Whenever the population density, urban unemployment rate, public budget expenditures for healthcare, and passenger traffic volume increase by 1%, the THCs' health resource allocation efficiency in the local province decreases by 0.2202, 3.6315, 0.0334, and 0.00003%, respectively. From the perspective of indirect effects, for every 1% increase in the population density and *per capita* healthcare expenditure ratio in neighboring areas, the efficiency of THC health resource allocation in the local province will increase by 0.3971 and 4.7213%, respectively. Whenever the urban unemployment rate and *per capita* disposable income in neighboring areas increase by 1%, the THCs' health resource allocation efficiency in the local province will decrease by 19.5882 and 0.0046%, respectively. From the total effect results of the interaction and cancellation between direct and indirect effects, the efficiency of total health resource allocation, PGDP, and *per capita* healthcare expenditure ratio increasing by 1% will, respectively, increase

TABLE 9 Spatial effect decomposition.

Variable	LR_Direct	P > z	LR_Indirect	P > z	LR_Total	P > z
X1	0.443793 1***	0.000	−0.068515 4	0.613	0.375277 7***	0.005
X2	−0.002201 8***	0.001	0.003971 1**	0.012	0.001769 3	0.280
X3	0.000021 3	0.248	−0.000044 4	0.275	−0.000023 1	0.573
X4	0.004738 6	0.248	0.001109 8	0.863	0.005848 4	0.409
X5	−0.005078 2	0.460	0.009615 9	0.387	0.004537 7	0.704
X6	0.000002 5***	0.004	0.000001 6	0.327	0.000004 2**	0.014
X7	−0.036314 6**	0.023	−0.195882 4***	0.000	−0.232197 1***	0.000
X8	0.000454 5	0.870	0.004319 1	0.446	0.004773 6	0.354
X9	0.000019 6***	0.000	−0.000046 2***	0.000	−0.000026 7***	0.006
X10	0.007879 1	0.414	0.047212 8***	0.006	0.055091 9***	0.008
X11	−0.000334 4***	0.000	0.000081 5	0.297	−0.000252 9***	0.003
X12	−0.000000 3*	0.081	0.000000 1	0.639	−0.000000 2	0.393
X13	0.014028 4	0.183	0.017311 4	0.360	0.031339 8	0.109

*p-value < 0.1, **p-value < 0.05, ***p-value < 0.01.

the THCs' health resource allocation efficiency by 37.5278, 0.0042, and 5.5092%. Whenever the registered urban unemployment rate, *per capita* disposable income, and public budget expenditures for healthcare increase by 1%, the efficiency of THC health resource allocation will decrease by 23.2197, 0.0027, and 0.0253%, respectively. To sum up, the efficiency of total health resource allocation, population density, PGDP, urban unemployment rate, per capital disposable income, per capital health expenditure ratio, public health budget, and passenger traffic volume are the key factors that affect the efficiency of health resource allocation in THCs. Therefore, Chinese provinces should fully consider and play the role of these influencing factors when improving the efficiency of health resource allocation in township health centers.

4.5 Insufficiencies

Firstly, there is still room for further improvement in the selection of variables. In theory, the healthcare market has the characteristics of multiple inputs and outputs with both expected and unexpected outputs coexisting (59). However, this study has not included some unexpected outputs such as medical expenses of outpatients and inpatients in the calculation of efficiency values yet, and some indicators that have been considered cannot comprehensively summarize the input–output situation of THCs.

Secondly, China's complete rural medical and healthcare network is a three-level healthcare structure that includes county-level hospitals, maternal and child health centers, disease prevention and control centers; township-level township health centers; village-level health centers, clinics, individual clinics, and many other institutions. However, this study only selected rural medical and health institutions THCs at the township level as the research objects, so the results of this study can only serve as a typical representative of the medical and health situation in rural areas of China.

Thirdly, this study found that the efficiency of total health resource allocation, which includes both urban and rural areas, has a significant impact on the efficiency of health resource allocation in rural TCH. We believe that the health resource allocation efficiency in urban areas will have an impact on the efficiency of rural health resource allocation. Although a brief discussion on this impact was included in the discussion section of this study, we are still unable to make a specific quantitative analysis, due to the inaccurate data. Future research on this topic may be considered.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: http://www.stats.gov.cn/sj/ndsj/.

Author contributions

NM: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. KS: Formal analysis, Validation, Writing – review & editing. XZ: Methodology, Conceptualization, Writing – review & editing. CL: Validation, Conceptualization, Writing – review & editing. XL: Data curation, Writing – review & editing. TP: Conceptualization, Writing – review & editing. DW: Formal analysis, Writing – review & editing. XM: Formal analysis, Methodology, Supervision, Writing – review & editing, Funding acquisition, Conceptualization, Project administration.

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Conflict of interest

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The efficiency evaluation of traditional Chinese medicine hospitals by data envelopment analysis in Zhengzhou, China

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Aim: This study aimed to evaluate the operational efficiency of traditional Chinese medicine (TCM) hospitals in China.

Methods: Pearson's analysis was used to test the correlation between the input and output variables. Data envelopment analysis (DEA) was utilized to analyze the input and output variables of 16 TCM hospitals, and each hospital efficiency score was computed by Deap 2.1, assuming variable return to scale (VRS), which is an input-oriented model. *t* tests were conducted to confirm the significant difference of efficiency scores at the hospital level and by hospital type, and ANOVA was used to test for significant differences in efficiency scores according to hospitals' size.

Results: The correlation coefficient of the input and output indicators was between 0.613 and 0.956 ($p < 0.05$). The difference in number of doctors (ND) and numbers of pharmacists (NP) were statistically significant ($p < 0.05$) at the hospital level. The mean efficiency scores for technical efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE) in secondary TCM hospitals were 0.766, 0.919, and 0.838, respectively. Additionally, the lowest TE, PTE, and SE were 0.380, 0.426, and 0.380, respectively. Eight TCM hospitals in this study were DEA efficient, with an efficiency score of 1. There were no statistically significant differences in TE, PTE, and SE among hospital levels, hospital types or hospital sizes groups ($p > 0.05$).

Conclusion: This study revealed that tertiary TCM hospitals had a greater level of efficiency than secondary TCM hospitals. In our study, 50% of TCM hospitals had inefficient management. Therefore, to activate the new development power of TCM hospitals, it is necessary to reform and improve the management system and mechanism of TCM hospitals, optimize the development environment of TCM hospitals and formulate development plans and measures based on local conditions.

KEYWORDS

data envelopment analysis, efficiency improvement, traditional Chinese medicine, operational efficiency, hospital efficiency

Introduction

Monitoring the performance of healthcare providers is a relevant and essential worldwide issue, especially in an overwhelming demand scenario. Efficiency refers to the minimum use of inputs for a certain level of output. Countries attach great importance to the input of financial, material, and human resources into hospitals (1). Evaluating the determinants of operational efficiency is beneficial for hospital managers to design appropriate organizational strategies to address the challenges related to continuous change and decreased waste of medical resources (2, 3), such as how to effectively utilize hospital resources during the SARS-CoV-2 pandemic. The pressure on health systems may exceed their predicted capacity to handle such extreme situations (4). For instance, a study conducted in Iran suggested that the outcome of the pandemic has been impacted due to outbreak response management efficiency, determining which countries' health systems perform better would be important by measuring the health efficiency of different countries during the COVID-19 epidemic (5).

There are several problems, including the rise in demand, the rapid growth of health expenses to incomes in developing countries and the lack of government budgets for hospitals (6). According to the World Health Report issued in 2014, 20–40% of all health sector resources are wasted (3). In China, the medical system has to maintain the health of 1.37 billion people (7, 8). Therefore, meeting the growing demand for health services in China is also a significant challenge. Previous studies conducted by different scholars have shown that the productivity and efficiency of hospitals need to be improved, especially for those secondary hospitals or those with fewer hospitals (9, 10). Effective operational evaluation benefits hospitals by identifying inefficiencies and prompting adjustments to promote their high-quality development (9). Recent research examining medical quality and operational efficiency in 57 tertiary general hospitals across China indicates a positive association between medical quality and technical efficiency (11). Additionally, another study analyzing the relationship between hospital efficiency and healthcare quality has found a positive correlation between regional hospital efficiency and healthcare quality, while the empirical evidence does not support the establishment of a causal relationship (12). By emphasizing the enhancement of healthcare service delivery and minimizing resource wastage, hospitals can attain higher levels of operational efficiency without compromising patient safety or the quality of care (13). This strategy not only promotes improved patient outcomes but also enhances the overall effectiveness and sustainability of healthcare delivery systems.

Traditional Chinese medicine hospitals (TCM hospitals), as one of the most important components of the healthcare system in China (14), have gradually established an important role in public health emergencies since the SARS-CoV-2 pandemic, such as being applied in-depth to epidemic prevention and control. In 2016, the outline of the "Healthy China 2030" emphasized that it is necessary to give full play to the characteristics of TCM, improve the service capacity of TCM and develop the health care service of TCM. In addition, the epidemic urged TCM hospitals to improve their services and emergency response capabilities, thereby allowing hospital managers to utilize medical source effectively to provide better medical services for patients. Whether TCM hospitals are public or not, it is necessary for them to use scientific and applied methods to assess the operational efficiency of the hospital for the optimal use of physical and human resources. This can be helpful in reasonably increasing hospital investment to ease the pressure of healthcare and obtain accurate information about the reasonable allocation of resources (3), thereby better maintaining or improving quality and patient safety.

Reviewing the previous literature, we found that data envelopment analysis (DEA) is a nonparametric linear programming method. It was first proposed by Farrel, and then developed by Charnes, Cooper and Rhodes (2, 3, 15, 16), who applied the CCR model to measure the technical efficiency of DMUs (decision-making units) based on the Pareto optimum concept (17). This method has been recognized as a powerful tool for performance analysis and benchmarking, spanning a wide range of industries and functional areas (18). In the medical system, it could be used to calculate the number of excess beds needed in hospitals in the case of an increase in the number of hospitalized patients during a pandemic (19), and it could also be helpful for identifying inefficient DMUs, which has a positive effect on promoting hospital improvement.

Numerous researchers from various countries have extensively utilized data envelopment analysis (DEA) to assess the efficiency of healthcare institutions in diverse contexts. Luca et al. studied the main organizational factors that generate hospital inefficiency and the internal and external features that affect hospital efficiency (2). Wang et al. identified the performance of maternal and child health hospitals in terms of productivity and efficiency (20). Yang et al. analyzed the effects of the global budgeting reimbursement system on productivity and financial efficiency by using a two-stage DEA model, thereby representing it as a key decision-making tool for hospital administrators and policymakers (17). By using DEA, Ergulen et al. estimated the effectiveness level of the Ministry of Health of the Republic of Turkey in fight of the COVID-19 epidemic, determining which months were productive or inefficient during this period (21). Mohamad et al. used this method to evaluate technical efficiency of 15 public hospitals to determine optimal hospital performance, and reported that hospital size is positively associated with technical efficiency (6). Shirouyehzad et al. created models by using DEA and MCDM methods to measure the efficiency levels of OECD countries during COVID-19 pandemic, finding six countries (Colombia, the USA, New Zealand, Denmark, and Slovakia) were efficient (5). Based on this, the purpose of this paper is to evaluate TCM hospital operational efficiency by data envelopment analysis (DEA) in Henan Province in 2020, hoping to provide appropriate advice and strategies for sustainable development of TCM hospitals in China.

Materials and methods

Sampling and data collection

Our study was conducted in Zhengzhou, China, which is a region located in northern China. There are 23 traditional Chinese medicine hospitals administered by the same governmental department, chosen to ensure a representative sample across various tiers of TCM healthcare facilities. We utilized a stratified proportion sampling technique to select the sampled hospitals in this study, sampling two in three facilities from ach stratum based on the type of hospital. Finally, 16 traditional Chinese hospitals were selected in this study, including four tertiary hospitals and 12 secondary hospitals. The letters represent the names of the TCM hospitals used in this study. This study was conducted in 2021, and the data in 2020 was collected for analyzing.

Data envelopment analysis (DEA) model: input-oriented model

DEA was selected due to its suitability for evaluating the relative efficiency of traditional Chinese medicine hospitals, considering multiple input and output measures simultaneously. Instead of measuring efficiency based on averages, the DEA model is more consistent with economic theory and locates technical or Pareto inefficiencies (22), which is a method for identifying and correcting the magnitudes of these inefficiencies (23). It is widely used for the evaluation of the relative efficiency and performance of a set of decision-making units (DMUs), usually including input and output orientations. This method does not need to have assumptions for determination of the production function, and a frontier function with the internal and external factors is constructed based on the information on the inputs and outputs of DMUs (5). For example, when hospital managers intend to more readily control the resources used for patient treatments (18) and focus on minimizing the use of inputs to produce a given output (24), a better choice is to adapt an input-oriented model. However, DMUs are given a fixed quantity of resources (inputs) and are asked to maximize output in the output-orientated DEA (25). In addition, we can estimate whether each hospital is efficient depending on its efficiency value, meaning that units with a score of 1 are considered effective, whereas other units with efficiency scores below 1 are called inefficient units (26). Specifically, we would identify related variables, like inputs variables (e.g., resources, staff) and outputs variables (e.g., Number of outpatient, bed utilization) and quantified for each hospital included in the analysis.

Researchers tend to choose suitable DEA models depending on their research purpose. For instance, the BCC model can be used to evaluate the relative efficiency of minimal input consumption for a given level of outputs, or the increase in output for a given input (17, 23). Many hospital providers are expected to provide a given level of healthcare services with the maximal resources. In other words, the primary purpose of analyzing hospital efficiency is to identify inefficient aspects that decrease hospital costs. Therefore, according to the aim of this study, an input-oriented model was used in this study, and a BCC model with variable-scale returns was chosen.

Input–output variables selection

Before starting this study, we reviewed the related literature related to hospital efficiency to acquire input–output variables, thereby providing good knowledge about what variables were essential and applied in existing studies. We found that the input variables included capital (e.g., equipment, hospital beds, etc.), land (e.g., area), labor (e.g., physician, nursing staff, etc.) and others; the outputs included patient, bed utilization, service and economic output. All of these factors are shown in Table 1.

The number of DMUs (Decision Making Units) should be double the total count of inputs and outputs combined, as argued by Dyson et al. (27). To meet this constraint and data accessibility, 8 variables were selected for the current study, as shown in Table 2. Some scholars have reported that Pearson analysis can be useful for measuring the significance of the linear correlation between input and output variables to test isotonicity (27–29). Before using this method, a homogeneity test of variance was performed by the Kolmogorov–Smirnov test, and all p values were over 0.05, indicating that Pearson analysis can be used to test the correlation between these input and output variables, and these results revealed strong correlations among them in this study. The correlation coefficients of the variables included in this study were shown in Table 2. Descriptive statistics of the inputs and outputs used in the analyses are presented in Table 3.

TABLE 1 Factors affecting hospital efficiency.

Inputs		Outputs	
Capital	Total beds (9, 14, 19, 26, 28, 35, 38, 39)	Patients	Number of outpatient or/and inpatient cases (6, 9, 10, 18, 30, 38)
	Number of existing beds (1, 29, 31)		Number of discharged patients (1, 3, 10, 14, 18, 26, 28–31, 34)
	Number of opening beds (1, 3, 6, 8, 10, 30, 34)		Number of outpatient and emergency patients (8, 31)
	Number of devices over 10,000 Chinese Yuan (1, 34)		Cured cases and improved cases (1, 39)
land	Structure/building/hospital area (1, 9, 34, 35)		Outpatient or/and emergency visits (1–3, 10, 26, 35)
Labor	Number of total staffs (1, 3, 6, 9)	Bed utilization	Outpatients per day (35)
	Number of health workers (1, 28, 29, 31, 39)		Days of hospital bed turnover (1)
	Number of doctors/physicians (1, 8, 10, 18, 19, 26, 30, 34, 35, 38)		Turnover times (1, 3)
	Number of TCM personnel (14)		Inpatient days/average length of stay (3, 6, 8, 26, 34, 35)
	Number of nurses (2, 8, 10, 18, 19, 26, 30, 34, 35, 38)		Working days of hospital beds (1)
	Pharmacists of western medicine (1)		Bed occupancy/utilization rate (1, 2, 19, 28, 30)
	Numbers of pharmacists (38)	Service	Number of health examinations (39)
	Numbers of other personnel (administrative, technical staff and logistic staff) (1, 2, 8, 19, 26, 35, 38)		Number of surgeries (6, 18, 26)
Others	Total expenditure (10, 30)	Others	Annual revenues of hospitals (26)
	Total assets (1, 30)/operating cost (2, 26)/subsidies (1)/total public funding (in dollar) (39)/total public funding (in dollar) (39)		Business revenue (1, 2)

TABLE 2 Correlation analysis of variables for input and output.

Inputs	Outputs	
	Number of outpatient and emergency patients (NOEP)	Number of discharged patients (NDP)
Number of opening beds (NOP)	0.865**	0.956**
Number of doctors (ND)	0.883**	0.899**
Number of TCM personnel (NTCMP)	0.923**	0.826**
Number of nurses (NN)	0.869**	0.928**
Numbers of pharmacists (NP)	0.850**	0.791**
Building area (BA)	0.613*	0.695**

*$p < 0.05$, **$p < 0.01$.

Data analysis

First, Pearson analysis was used to test the correlation between the input and output variables to determine which variables could be chosen in this study. Then, DEA was used to analyze the input–output variables of all TCM hospitals that we selected, and each hospital efficiency score was computed by Deap 2.1, assuming variables return to scale (VRS), which is an input-oriented model. Previous studies mentioned that hospital characteristics (including size and ownership type) influence efficiency (6, 18, 26). TCM hospital ownership types were divided in our study, including public and nonpublic. According to a previous study, we found that there were three types of hospital sizes: small (fewer than 500 beds), medium (500–1,000 beds) and large (more than 1,000 beds) (18), the same method of division was used to determine hospital size in this study. In this study, ANOVA *F*-tests or t tests were conducted to confirm the significant differences in TCM hospital ownership type and hospital size.

Ethics

The participants in this study did not focus on human beings, and there was no relationship between the data collected and the patients' medical records. Therefore, an ethics statement was not needed.

Results

Correlation analysis

According to correlation analysis, we found that all correlation coefficients were greater than 0.600, indicating that there was a strong positive correlation between the input and output variables ($p < 0.05$). The correlation coefficient of the input–output indicators was between 0.613 and 0.956, as shown in Table 2.

Basic characteristics of the sample TCM hospitals

Sixteen TCM hospitals were selected in this study, including four tertiary hospitals and 12 secondary hospitals. The variables for the inputs and outputs are shown in Table 3. For tertiary hospitals, the average numbers of opening beds and building areas were 691.750 and 41,803.750 m^2, respectively. The average numbers of health workers were doctors (260.250), TCM personnel (139.500), nurses (411.500) and pharmacists (40.250), respectively. For secondary hospitals, the average number of outpatient and emergency patients was 297,998.000, and the average number of discharged patients was 19,988.000. Comparing the variables of inputs and outputs between tertiary hospitals and secondary hospitals, the difference in ND and NP was statistically significant ($p < 0.05$), and there was no significant difference in the other six items ($p > 0.05$).

Operational efficiency of TCM hospitals

DEA-BCC was conducted for the two data groups. The letters represent the names of the TCM hospitals, and the results are presented in Table 4. A–D were used to represent four tertiary TCM hospitals, including three general public hospitals and one specialized non-public hospital, and all of these TCM hospitals had an efficiency score of 1, meaning that these hospitals were on the efficient production frontier.

E–P represents 12 secondary TCM hospitals, including four general public hospitals, seven general non-public hospitals and one specialized non-public hospitals. The mean efficiency scores of TE, PTE, and SE in secondary TCM hospitals were 0.766, 0.919, and 0.838, respectively. Additionally, among TCM secondary hospitals, we found that only four hospitals acquired efficient scores, with an efficiency score of 1. Two hospitals had efficiency scores ranging from 0.8 to 1, representing weekly efficiency. Besides, three hospitals had efficiency scores lower than 0.5, which here classified as extremely inefficient. The lowest TE, PTE, and SE efficiency scores were 0.380, 0.426, and 0.380, respectively.

Eight TCM hospitals (A, B, C, D, F, I, N, and P) were DEA efficient, and the returns to scale were constant (−), meaning that the development of these hospitals entered a stable period. Maintaining the dynamic balance of input and output can guarantee their stable development. In secondary hospitals, the return to scale of 8 hospitals (E, G, H, J, K, L, M, and O) increased (inputs should be increased to improve efficiency). Eight TCM hospitals had constant returns to scale (changes in the number of inputs did not affect efficiency), and 50% of TCM hospitals showed an increase in returns to scale.

TABLE 3 Descriptive statistics for the sample TCM hospitals.

Code	Explanation of the variable	Tertiary hospital			Secondary hospital		
		N	Mean	SD	*N*	Mean	SD
Input variables							
NOB	Number of opening beds	4	691.750	439.643	12	294.83	318.181
ND	Number of doctors	4	260.250	199.326	12	91.250	93.522
NTCMP	Number of TCM personnel	4	139.500	126.221	12	55.500	55.841
NN	Number of nurses	4	411.500	357.501	12	154.750	164.130
NP	Numbers of pharmacists	4	40.250	20.694	12	14.000	12.563
BA	Building area	4	41,803.750	22,215.957	12	26,461.417	33,612.814
Output variables							
AOEP	Number of outpatient and emergency patients	4	297,998.000	368,206.877	12	98,696.667	120,539.210
NNP	Number of discharged patients	4	19,988.000	13,157.814	12	8,276.000	11,712.093

TABLE 4 The scores of the efficiency of TCM hospitals by DEA.

Hospital type		DMUs	TE	PTE	SE	RS
Tertiary TCM hospital	Public	A	**1.000**	**1.000**	**1.000**	–
		B	**1.000**	**1.000**	**1.000**	–
		C	**1.000**	**1.000**	**1.000**	–
	No-public	D	**1.000**	**1.000**	**1.000**	–
Secondary TCM hospital	Public	E	0.386	0.426	0.905	irs
		F	**1.000**	**1.000**	**1.000**	–
		G	0.697	0.700	0.995	irs
		H	0.480	0.904	0.531	irs
	No-public	I	**1.000**	**1.000**	**1.000**	–
		J	0.380	1.000	0.380	irs
		K	0.855	1.000	0.855	irs
		L	0.900	1.000	0.900	irs
		M	0.935	1.000	0.935	irs
		N	**1.000**	**1.000**	**1.000**	–
		O	0.560	1.000	0.560	irs
		P	**1.000**	**1.000**	**1.000**	–

DUMs, Decision making units; TE, Technical efficiency; PTE, Pure technical efficiency; SE, Scale efficiency; RS, Return to scale; irs: Increasing; –: constant. The meaning of bold values suggested these hospitals were on the efficient production frontier.

The differences in hospital efficiency scores according to hospital characteristics

According to the *t* test and *F* test, we found that there were no statistically significant differences in TE, PTE, and SE among hospital levels, hospital types or hospital sizes groups ($p > 0.05$), as shown in Table 5.

Discussion

TCM hospitals play an important role in health systems, and it is essential for health providers to maintain sustainable development. Especially during the pandemic, demand for health services increased, and TCM hospitals were forced to increase the capacity of their resources owing to pressure on the health system, such as the number of hospital beds and health workers available for handling such a special situation. Evaluating TCM operational efficiency can be helpful in identifying inefficiency sources, thereby making it possible to reduce hospital costs and decrease wastage of hospital sources. On the other hand, the optimal utilization of hospital capacity and inputs is more efficient than building new hospitals to meet the needs of patients (19). According to our analysis of the efficiency of TCM hospitals during the pandemic, knowledge of their operational status can be used to identify inefficiency parts in helping hospitals to effectively allocate resources.

Comparing the input and output variables between tertiary hospitals and secondary hospitals, revealed that the difference in the number of doctors and pharmacists was statistically significant ($p < 0.05$). Additionally, we found that the average numbers of doctors and pharmacists in tertiary TCM hospitals were 260.250 and 40.250, respectively, which were much higher than the average numbers in secondary hospitals (91.250 and 14.000, respectively). A previous study reported that there was a statistically significant difference in the number of outpatient visits to tertiary hospitals ($p < 0.05$) (9), while we found that the difference in the number of outpatient and emergency patients was not statistically significant ($p > 0.05$). By using BCC-DEA, we found that all tertiary TCM hospitals in our study had an efficiency score of 1, which was in line with the findings of Li et al. (9). 50% of TCM hospitals had inefficient management in our study, which was higher than that reported in an Iranian study conducted by Soroush et al. (19) and lower than the findings of in other studies (2, 3, 6, 30, 31). A study has shown a different result that the overall effective rate of secondary public hospitals (30.77%) was higher that of tertiary public hospitals (19.44%) (32). Moreover, a study conducted by Li in China revealed that the mean efficiency scores of TE, PTE, and SE among TCM hospitals in China were 0.870, 0.911, and 0.957 (29), which were higher than the mean efficiency scores of TE and SE of secondary TCM hospitals in our study, suggesting that the hospitals in our study operated at low efficiency. Meanwhile, these results reflected that tertiary hospitals have a greater level of efficiency than secondary hospitals, which was consistent with the results of some studies (9, 33). Additionally, three secondary TCM

TABLE 5 Differences in hospital efficiency scores according to hospital characteristics.

		Number of hospitals (*n*)	TE	PTE	SE
Hospital level	Tertiary TCM hospital	4	1 (0.000)	1 (0.000)	1 (0.000)
	Secondary TCM hospital	12	0.767 (0.251)	0.919 (0.178)	0.838 (0.219)
	t		1.817	0.885	1.440
	p value		0.091	0.391	0.172
Ownership type	Public	7	0.795 (0.272)	0.861 (0.221)	0.918 (0.175)
	Non-public	9	0.848 (0.225)	1 (0.000)	0.848 (0.225)
	t		−0.428	−1.897	0.687
	p value		0.675	0.079	0.489
Hospital size	Less than 500 beds	2	0.811 (0.242)	0.990 (0.030)	0.816 (0.235)
	500–1,000 beds	4	0.771 (0.294)	0.782 (0.276)	0.975 (0.047)
	More than 1,000 beds	10	1 (0.000)	1 (0.000)	1 (0.000)
	F		0.621	3.653	1.370
	p value		0.553	0.055	0.288

TE, Technical efficiency; PTE, Pure technical efficiency; SE, Scale efficiency.

hospitals had efficiency scores lower than 0.5 in our study, and TEs and SEs among them had the lowest scores, meaning that this TCM hospital had a severely inefficient technical level. This can be explained by the fact that tertiary hospitals have stronger superiority than secondary hospitals in local policy financial investment, medical capacity, and competition for patient resources. Under this poor background, it is necessary to seek for some ways for improving comprehensive ability of secondary hospitals, such as signing contracts with large hospitals, forming specialty alliances or medical alliances, thereby making it possible to strength their operational efficiency. Besides, the results had also indicated considerable room for TE improvement in secondary TCM hospitals. Such measures like procurement of low-cost and high-quality medical equipment and supplies could be referenced for improving efficiency of hospitals.

The difference in efficiency between secondary and tertiary hospitals mainly came from differences in the management level of hospital managers and the technical level of doctors. For example, previous literature revealed that the proportion of health professionals had a positive association with efficiency scores (25). Some scholars believe that medical personnel prefer to work in high-level hospitals for better conditions, higher salaries, and bright development prospects (9, 25). Moreover, the national policy of emphasizing western medicine and neglecting TCM may be a key factor that leads to a deterioration in the development of TCM hospitals (9). Therefore, as the main providers of TCM, TCM hospitals should consider corresponding policies and measures to improve their efficiency for stable development, especially for secondary TCM hospitals. For example, hospitals can optimize the personnel structure by increasing healthcare workers with high-quality and reducing these employees with less-skilled.

Previous studies have shown that TCM hospitals with low PTE should focus on improving hospital management and decision-making, and TCM hospitals with low SE should emphasize appropriately carrying out scale operation construction as their keystone (31, 34) Additionally, the efficiency of TCM hospitals is a great way to determine information related to the state of hospital operation, which is beneficial for making reasonable decisions for the development of hospitals. These measures, such as learning up-to-date management system concepts, optimizing hospital operation scales, and effective allocation, can be important for improving the technological capability and management ability of hospitals.

Comparing DEA scores at different hospital levels can be helpful for explaining, to some extent, the development of medical and health resources at different levels. Analysis of the differences in TE, PTE, and SE between secondary and tertiary TCM hospitals revealed that there was no significant difference in the level of hospitals, which was inconsistent with previous research showing that the difference in PTE between secondary and tertiary hospitals was statistically significant (9). Mohamad et al. (6) reported similar results using Tobit regression. We found that hospital type was a nonsignificant driver of efficiency in our study, which was in line with the findings of Luca et al. (2) and Xing et al. (35) In addition, we found that there was no significant difference between hospital size and efficiency scores in this study, which does not align with the findings that increasing the number of hospital beds could improve the TE value of hospitals with different bed sizes (31, 36) or that the size of the hospital had a significant effect on hospital efficiency (2, 6, 37). The findings of a study on the efficiency assessment of tertiary hospitals in China showed that the suitable number of beds in the hospital was 1,001–2,000 beds (31).

In analyzing hospital efficiency, different scholars intend to choose different indicators, making it possible to obtain different results. There were several limitations in this study. First, TCM hospitals, which are representative of hospitals in that city, were evaluated for only 1 year in this study. Second, some environmental factors that affect the efficiency of TCM hospitals, such as local economic level, and health service costs, had not been analyzed. Third, the selected variables may not be perfect, although we reviewed indicators related to hospital efficiency according to previous literature. Fourth, we were unable to assess the role of environmental factors such as population size and poverty due to a lack of available data. Therefore, further research on TCM hospitals in other regions is needed to better understand the efficiency of TCM hospitals in China. In addition, the indicators did not exhibit significant differentiation between

traditional Chinese medicine (TCM) hospitals and Western medicine hospitals. Furthermore, we aim to investigate prospective strategies aimed at bolstering their resilience amidst these evolving circumstances in forthcoming researches.

Conclusion

This study measured the TE, PTE, and SE of municipal TCM hospitals by using the DEA-BCC model, the main finding of which was tertiary TCM hospitals have a higher level of efficiency than secondary TCM hospitals. In our study, 50% of TCM hospitals had inefficient management. In addition, there were no statistically significant differences in TE, PTE, and SE among hospital levels, hospital types or hospital sizes groups ($p > 0.05$). Therefore, to activate the new development power of TCM hospitals, it is necessary to reform and improve the management system and mechanism of TCM hospitals, optimize the development environment of TCM hospitals and formulate development plans and measures based on local conditions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

JW: Methodology, Writing – original draft, Writing – review & editing. HL: Conceptualization, Methodology, Writing – review & editing. HJ: Writing – review & editing. WR: Conceptualization, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Regional differences, dynamic evolution, and influencing factors of high-quality medical resources in China's ethnic minority areas

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Background: In China, as people's standard of living improves and the medical service system becomes more sophisticated, the demand for higher-quality and improved healthcare services is steadily rising. Inequality in health resource allocation (HRA) is more pronounced in ethnic minority areas (EMAs) than in developed regions. However, little research exists on high-quality medical resources (HQMRs) in China's EMAs. Hence, we examined the spatiotemporal dynamic evolution of HQMRs in China's EMAs from 2007 to 2021 and identified the main factors affecting their respective HQMR levels.

Methods: We selected tertiary hospitals to represent the quality of healthcare resources. We employed descriptive statistical techniques to analyze changes in the distribution of HQMRs from 2007 to 2021. We used the Dagum Gini coefficient and kernel density approach to analyze the dynamic evolution of HQMRs in China's EMAs. We utilized the least squares dummy variable coefficient (LSDVC) to identify key factors affecting HQMR.

Results: The number of HQMRs in each EMA has risen annually. The average number of tertiary hospitals increased from 175 in 2007 to 488 in 2021. The results of the Dagum Gini coefficient revealed that the differences in the HQMR level in China's EMAs have slowly declined, and intra-regional disparities have now become the primary determining factor influencing overall variations. The kernel density plot indicated that the HQMR level improved significantly during the study period, but bifurcation became increasingly severe. Using the LSDVC for analysis, we found that gross domestic product (GDP) *per capita*, the size of the resident population, and the number of students enrolled in general higher education exhibited a significant negative correlation with HQMR levels, while GDP and urbanization rate had a significant promoting effect.

Conclusion: The HQMR level in EMAs has risen rapidly but remains inadequate. The differences in HQMR between regions have continued to narrow, but serious bifurcation has occurred. Policymakers should consider economic growth, education, and population size rather than simply increasing the number of HQMRs everywhere.

KEYWORDS

China, ethnic minority areas, health resource allocation, high-quality medical resources, dynamic evolution of resources

1 Background

Health is a fundamental desire and basic necessity for all human beings (1), and health resources are the basis for promoting sustainable social development and maintaining people's well-being (2). Medical resources constitute a crucial component of healthcare services and resources (3). Fair and effective allocation of medical resources is critical to promoting the expansion of public health (4). In the 2030 Agenda for Sustainable Development, the United Nations emphasized "ensuring universal access to health and healthcare services and achieving universal health coverage" as a key goal. At present, the unfair distribution of medical and health resources (MHRs) has become a global problem (5), especially in developing countries. For example, Hu et al. found that among the seven types of essential public services in China, the imbalance between the supply of and demand for medical and health services is recognizable (6).

Hence, the balance and sustainability of health resource allocation have attracted widespread attention in China. In 2009, China embarked on a new round of reforms of its medical and health system, and made substantial breakthroughs in solving the imbalance of health resource allocation and promoting the balanced distribution of regional health resources. However, with the improvement of living standards and the continuous improvement of the medical system, the existing health resources are no longer sufficient to meet the people's diverse and multi-level demand for medical services. The people's demand for high-quality medical resources (HQMR) is becoming increasingly urgent (7). However, owing to the limited level of economic growth and the uneven spatial distribution of health resources (7, 8), the disparity in medical services between urban and rural areas and across different regions continues to be prominent (8–11). As HQMRs cannot cover the entire population, People are compelled to relocate across regions to access higher-quality medical and healthcare services, which may exacerbate pre-existing social issues, increase the cost of healthcare access (12), and directly violate the right to health for some populations (13).

The balanced allocation of HQMRs has always been the focus of national healthcare. HQMRs function within a broader medical service network, including excellent medical talent, advanced medical techniques, first-rate instruments and equipment, and advanced medical information systems (14). In 2016, the Chinese government released the *Healthy China 2030 Plan*, which aims to "achieve a balanced distribution of high-quality medical care and health resources" (15). In March 2021, China published its *14th Five-Year Plan for National Economic and Social Development* (2021–2025) as well as its *Outline of Long-term Goals*. A proposal has been put forth to expedite the expansion of HQMRs and to guarantee an equitable distribution of resources across various regions of the country (16). An investigation into regional differences in the level of high-quality medical treatment across China will help scholars to accurately understand the unbalanced allocation of HQMRs; such research is critical to advancing health system reforms.

Abbreviations: DEA, data envelopment analysis; EMA, ethnic minority area; GDP, gross domestic product; GIS, geographic information system; GMM, generalized method of moments; HQMR, high-quality medical resources; HRA, health resource allocation; LSDVC, least squares dummy variable coefficient; MHSS, medical and health service supply; MHRs, medical and human resources; OLS, ordinary least squares.

At present, studies have fully recognized that the imbalance in the allocation of health resources is a serious health service challenge facing China, but most of them focus on the following aspects. First, it focuses on analyzing the geographical differences in the allocation of health resources in China from the horizontal perspective. In addition, Wan et al. used medical geography big data to analyze the spatial clustering patterns and spatial heterogeneity of medical resources in China (17). TongWang et al. evaluated the fairness of the allocation of medical and health resources in rural China from a macro perspective and compared the differences in fairness between the eastern, central and western regions in China (18). In addition, there are some non-state-level studies that analyze the inequality and disparity of health resource allocation in specific regions of China (19–22). The second is to analyze from a longitudinal dimension, focusing on the spatial–temporal evolution and sustainable development of health resource allocation (23). Shen et al. analyzed the spatial and temporal evolution trends and spatial agglomeration changes of medical and health resources in 41 cities in the Yangtze River Delta region of China from 2007 to 2019 (24). Chen et al. measured the level of medical and health service supply (MHSS) in 31 provinces in China from 2005 to 2020, and further studied the spatial distribution changes and dynamic evolution trends of MHSS (12). Overall, there have been many studies on the fairness of China's health resource allocation, covering a wide range of dimensions. However, there have been few studies on regional differences in HQMR and the factors influencing them. Only a few scholars have studied China's HQMR allocation and influencing factors at the national level, and there is a lack of systematic analysis of the fairness of HQMR allocation in specific regions (25).

Most of the recent related research has focused on China because China is a multi-ethnic country, with ethnic minorities concentrated along the borders and in remote parts of the country's northwest and southwest regions, including Guizhou Province, Yunnan Province, Qingha Province, the Guangxi Zhuang Autonomous Region, the Ningxia Hui Autonomous Region, the Xinjiang Uyghur Autonomous Region, the Inner Mongolia Autonomous Region, and the Tibet Autonomous Region (26). Compared with the eastern and central regions, China's ethnic minority areas (EMAs) are sparsely populated and underdeveloped in terms of economics and medical service provision. According to existing studies (27, 28), the quality, quantity, and fairness of health resources in EMAs are lower than those in other developed areas, and health resources and inequality persist (29), especially in terms of high-quality medical resources, there is still a large gap with other regions. This suggests that more attention should be paid to the specific situation and influencing factors of the allocation of HQMR in western China, in order to promote the expansion and sinking of HQMR in ethnic areas and promote the coordinated development of regional medical and health care. However, few studies have focused on the allocation of health resources in ethnic areas in China.

As far as we know, this is the first study on the dynamic evolution and influencing factors of the allocation of HQMR in ethnic areas. It can provide some inspiration for how to improve the allocation of HQMR in ethnic minority areas and other similar situations. The following are potential innovations from this study. First, this study uses the Dagum Gini coefficient and kernel density estimation to analyze the regional differences and dynamic evolution of the HQMR level in ethnic areas. These two methods utilize visualization techniques, such as

three-dimensional graphs and line graphs, to more vividly and specifically illustrate the temporal and spatial evolution of health resources. Second, this study uses the LSDVC method to analyze the factors influencing the level of HQMR in ethnic areas, which can effectively solve the problem of endogeneity and is more suitable for the long panel data of this study. Finally, the analysis of influencing factors from multiple dimensions, such as economic development level, demographic characteristics, education level, and policy support, is of practical significance for guiding the government to implement precise policies.

2 Materials and methods

We relied on descriptive statistics to address changes in the HQMR distribution from 2007 to 2021. We used the Dagum Gini coefficient decomposition method to analyze regional differences in the HQMR distribution in EMAs, and visualized the distribution characteristics and evolutionary trends of HQMRs from 2007 to 2021 using kernel density estimation. We used MATLAB to draw a 3D kernel density map, and the least squares dummy variable coefficient (LSDVC) to identify key factors affecting the HQMR distribution.

2.1 Statistical methods

2.1.1 The Dagum Gini coefficient

Decomposition methods are commonly used to measure regional differences, including the Theil index, the coefficient of variation, and the Gini coefficient; however, these approaches cannot further decompose regional disparities and compare the distribution of subsamples (30). The Dagum Gini coefficient can decompose a region into multiple sub-regions and calculate the total difference, intra-region difference, inter-region difference, and hypervariable density, thus breaking the above constraints more effectively. The specific equation of the Dagum Gini coefficient is as follows:

$$G = \frac{\sum_{j=1}^{k}\sum_{h=1}^{k}\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}\left|y_{ji} - y_{hr}\right|}{2n^2\bar{y}} \tag{1}$$

$$\overleftarrow{Y}_h \le \cdots \overleftarrow{Y}_j \le \cdots \overleftarrow{Y}_k \tag{2}$$

In Equation 1, G denotes the overall Gini coefficient; n represents eight provinces categorized as EMAs; k refers to the number of secondary regions in the sample; yji (yhr) is the number of HQMRs in region j (h); $\bar{y}$ indicates the average value of an HQMR; nj (nh) is the number of provinces in region j (h); and r denotes the different provinces in region j (h). When the Gini coefficient is decomposed, the average of each region is sorted according to Equation 2.

According to the Dagum Gini coefficient decomposition method (31), the overall Gini coefficient G is divided into three parts: (1) the contribution of differences within regions Gw; (2) the contribution of differences between regions Gnb; and (3) the contribution of anti-variation intensity Gt, which satisfies $G = Gw + Gnb + Gt$. They are displayed in Equations 3–7:

$$G_w = \sum_{j=1}^{k} G_{jj} p_j s_j \tag{3}$$

$$G_{nb} = \sum_{j=2}^{k}\sum_{h=1}^{j-1} G_{jh}\left(p_j s_h + p_h s_j\right) D_{jh} \tag{4}$$

$$G_t = \sum_{j=2}^{k}\sum_{h=1}^{j-1} G_{jh}\left(p_j s_h + p_h s_j\right)\left(1 - D_{jh}\right) \tag{5}$$

$$G_{jj} = \frac{\sum_{i=1}^{n_j}\sum_{r=1}^{n_j}\left|y_{ji} - y_{hr}\right|}{2n_j^2\bar{y}_j} \tag{6}$$

$$G_{jh} = \frac{\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}\left|y_{ji} - y_{hr}\right|}{n_j n_h\left(\bar{y}_j + \bar{y}_h\right)} \tag{7}$$

Gjj indicates the Gini coefficient in region j and Gjh denotes the inter-regional Gini coefficient in regions j and h. Djh is the relative influence between regions i and j using Equation 8.

$$D_{jh} = \frac{d_{jh} - p_{jh}}{d_{jh} + p_{jh}} \tag{8}$$

The calculation formulas for djh and pjh are shown in Equations 9, 10, respectively, where djh is the difference in values between regions, and Fh (Fj) represents the cumulative density distribution function for region j. The equations read as follows:

$$d_{jh} = \int_0^{\infty} dF_j(y)\int_0^{y}(y - x)dF_h(x) \tag{9}$$

$$p_{jh} = \int_0^{\infty} dF_h(y)\int_0^{y}(y - x)dF_j(x) \tag{10}$$

2.1.2 Nuclear density estimation

Kernel density estimation is an important non-parametric estimation technique that uses a smoothed peak function to fit the sample data as well as a continuous density curve to describe the distribution of random variables, which can reflect the distribution position, shape and ductility of random variables (32). The density function of random variable X is shown in Equation 11:

$$f(x) = \frac{1}{Nh}\sum_{i=1}^{N} K\left(\frac{X_i - x}{h}\right) \tag{11}$$

N is the number of observations; X is the HQMR average; K is the kernel function; and h is the bandwidth. The kernel function does not greatly affect the shape of the curve, but it does affect the smoothness.

The choice of bandwidth determines the shape of the curve. The larger the bandwidth, the smaller the variance of the kernel density estimate. In this study, we adopted a smoother Gaussian kernel and used kernel density estimation to explain the dynamic evolution of the HQMR distribution in EMAs from four perspectives (33): (1) distribution position; (2) shape; (3) ductility; and (4) polarization of the curve.

2.1.2.1 Econometric dynamic panel model

In general, a generic panel model can be used, which can be divided into fixed effects (FEs) and random effects (REs). The specific formula is shown in Equation 12:

$$Y_{it} = \alpha + X_{it}\beta + Z_i'\delta + u_i + \varepsilon_{it} \left(i = 1, \cdots ,,,,,n; t = 1, \cdots , T\right) \quad (12)$$

Yit is the number of HQMRs in EMAs; *Zi* is the individual feature that does not change with time; *Xit* is the individual and time-based change; *ui* is the individual effect; and *εit* is the residual disturbance term. If the *ui* is related to an explanatory variable, it is a FEs model. If the *ui* is independent of all explanatory variables, it is a REs model.

In many studies, the inertia of the dependent variable (34) is often ignored. If the lag term of the dependent variable is added as an explanatory variable. The model is shown in the Equation 13:

$$Y_{it} = \alpha + \rho Y_{i,t-1} + X_{it}'\beta + Z_i'\delta + u_i + \varepsilon_{it} \left(i = 1, \cdots , n;\ t = 2, \cdots , T\right) \quad (13)$$

Using this dynamic panel model estimation will introduce dynamic panel bias, which is usually estimated by the difference GMM and the system GMM. We eliminated individual effects by creating first-order differences. The specific formula is shown in the Equation 14:

$$\Delta Y_{it} = \rho \Delta Y_{i,t-1} + \Delta X_{it}'\beta + \Delta\varepsilon_{it} \left(i = 1, \cdots , n; t = 2, \cdots , T\right) \quad (14)$$

When the sample's features are small, the performance of the system GMM estimation is poor (i.e., the small-sample bias problem). Since the 15-year data selected for this study are long-term, the group is long-term and contains only eight provinces, and the panel size is small, estimation with systematic GMM regression may lead to small sample bias. Thus, we selected the bias-corrected least squares false variable (i.e., LSDVC), proposed by Bruno in 2005 (35), to accommodate unbalanced panels. The idea is to use the LSDVC to estimate the dynamic panel model as well as the bias of the LSDVC, and finally to subtract bias from the estimate of the LSDVC to achieve a consistent estimate (36). Based on prior research, we used the LSDVC estimator with FEs; it is stable in the presence of non-equilibrium panels, first-order sequence correlation, and set unobservable heterogeneity in the dynamic panel. We predicted the LSDVC estimator for initial dynamic panel estimation, which depends on the accuracy of $N^{-1}T^{-2}$ and adopts the values of the system GMM estimate and the differential GMM estimate as the initial estimates.

2.2 Description of the data for the variables

We obtained data on the quality of medical resources and factors affecting the HQMR distribution in EMAs from 2007 to 2021 from the *China Health Statistics Yearbook*, published by the National Health Commission of China, and the *China Statistical Yearbook*, published by the National Bureau of Statistics.

Tertiary hospitals are the highest-ranking medical institutions in China's existing medical service system; they tend to offer better medical services and management, medical quality and safety, an adequate technical level, and efficiency (37). Hence, we selected the number of tertiary hospitals in each province to represent the HQMR level.

The spatiotemporal variation of the HQMR distribution is a dynamic process supported by many factors. Based on relevant results (1–4), we mainly considered the impact of four elements: (1) demographic structure, (2) level of economic development, (3) education level, and (4) medical and health spending.

2.2.1 Demographic structure

The size of the permanent resident population has a significant impact on the spatial distribution of HQMRs in China; hence, this variable was selected to represent the demographic structure. Gerdtham asserted that with an improved urbanization, more people could effectively receive high-quality medical and health services (38). In the present study, we used the urbanization rate to represent the level of urbanization.

2.2.2 Level of economic development

This element significantly impacts the development of medical and health undertakings. We adopted GDP, and *per capita* GDP.

2.2.3 Education level

There is a close link between residents' education level and health status (39). The ultimate goal of the development of medical and health undertakings is to improve residents' health. We used the number of students in colleges and universities per 100,000 people and the illiteracy rate to indicate education level. The illiteracy rate is inversely proportional, whereas the number of students in colleges and universities per 100,000 people is directly proportional to the education level.

2.2.4 Government policy support

Government policy support plays a very important role in the allocation of medical resources. Intergovernmental transfer payments are mainly used to balance the differences in government revenue between regions due to differences in geographical environment or economic development levels. Government medical and health spending is crucial for measuring the development of medical and health undertakings. We use government transfer payments and government health expenditures to indicate the strength of policy support.

In sum, we selected nine indicators from the four elements (see Table 1 for details).

3 Results

3.1 The basic distribution of HQMRs in EMAs from 2007 to 2021

As seen in Table 2, the total amount of HQMRs in EMAs is denoted by a linear growth trend from 2007 to 2022. The number of tertiary hospitals rose from 175 in 2007 to 488 in 2021. The

TABLE 1 Explanatory variables.

Factor	Specific index	Unit	Factor code
Demographic structure	Permanent population size	10,000 people	X1
	Population density	People/km^2	X2
	Urbanization rate	%	X3
Economic development	local finance revenue in the general budget sector	Ten thousand yuan	X4
	GDP	Hundred million yuan	X5
	Per capita GDP	Ten thousand yuan	X6
Policy support	Government health spending	Ten thousand yuan	X7
Education level	Illiteracy rate	%	X8
	Number of students enrolled in regular higher education institutions per 100,000 people	People	X9

TABLE 2 HQMR trends in EMAs from 2007 to 2022.

Province	2007	2012	2017	2021	Growth rate
Inner Mongolia Autonomous Region	35	33	67	91	160%
Guangxi Zhuang Autonomous Region	46	50	63	94	104%
Guizhou Province	22	27	49	79	259%
Yunnan Province	36	40	67	107	197%
Tibet Autonomous Region	2	2	7	17	750%
Qinghai Province	8	10	16	25	213%
Ningxia Hui Autonomous Region	6	4	13	19	217%
Xinjiang Uygur Autonomous Region	20	18	35	56	180%
EMA	175	184	317	488	179%

EMA, ethnic minority area.

growth rate was 179%, with an average increase of 20.86 hospitals per year. Among them, the natural growth rate of Inner Mongolia and Guangxi was lower than the average of EMAs at 160 and 104%, this is mainly because it has a relatively high level of high-quality medical resources. The rest of the region was above average, and the highest was 750% in Tibet. In terms of stages, the number of tertiary medical institutions showed a slow growth or even negative growth trend during the period from 2007 to 2010. This period coincided with the initial stage of China's medical reform, and the drastic fluctuations in the implementation of new policies led to fluctuations in the allocation of high-quality medical resources. During the period from 2010 to 201 During the period from 2010 to 2019, with the continuous improvement of medical reform policies, especially after the launch of the public hospital reform in 2010, the number of tertiary medical institutions showed a rapid upward trend, and the development trend was obvious. From 2020 to 2021, due to the impact of the epidemic, the growth rate of tertiary medical institutions slowed down, but it continued to increase. Overall, the level of high-quality medical resources allocation in ethnic minority areas showed a fluctuating upward trend.

Regarding the distribution of HQMRs in EMAs in 2021, there were 488 tertiary hospitals, averaging 61 per region. According to the geographic division, national areas are divided into two regions: northwest and southwest. The total amount of HQMRs in southwest China (297) was higher than that in northwest China (191). From a provincial perspective, Inner Mongolia, Guangxi, and Yunnan had more than 90 tertiary hospitals, with 91, 94, and 107, respectively. Four regions had a below-average number of tertiary hospitals, with Tibet and Ningxia having the fewest at 17 and 19, respectively. This is basically consistent with the ranking of economic development and population size in the provinces of ethnic areas, indicating that economic and demographic factors may have a greater impact on the level of high-quality medical resources and should be given priority consideration in future research. Further details are presented in Table 3.

In 2021, the average number of tertiary hospitals per million people in EMAs was 2.41. In terms of provinces, Xizang had the highest number of hospitals (4.64), while Guangxi had the fewest (1.87). In four regions (Guangxi, Guizhou, Yunnan, and Xinjiang), the number of tertiary hospitals per million people was lower than their average level in EMAs. In 2021, the average number of tertiary hospitals per 10,000 km^2 in EMAs was 0.86. From a regional standpoint, the average level in the southwest (1.47) was much higher than that in the northwest (0.53), contrary to the outcome of the number of tertiary hospitals per million people. As for the number of tertiary hospitals per 10,000 km^2, the top three provinces were Guangxi (3.98), Guizhou (4.49), and Ningxia (2.86), while for Tibet,

TABLE 3 The HQMR distribution in China in 2021.

District	Province	Permanent population (10,000 people)	Total area (km^2)	# of tertiary hospitals	Tertiary hospital	
					Per million people	Every 10,000 km^2
Southwest	Guangxi Zhuang Autonomous Region	5,037	23.6	94	1.87	3.98
	Guizhou Province	3,852	17.6	79	2.05	4.49
	Yunnan Province	4,690	38.33	107	2.28	2.79
	Tibet Autonomous Region	366	122.8	17	4.64	0.14
	Southwest	13,945	202.33	297	2.13	1.47
Northwest	Inner Mongolia Autonomous Region	2,400	118.3	91	3.79	0.77
	Qinghai Province	594	72.23	25	4.21	0.35
	Ningxia Hui Autonomous Region	725	6.64	19	2.62	2.86
	Xinjiang Uygur Autonomous Region	2,589	166	56	2.16	0.34
	Northwest	6,308	363.17	191	3.03	0.53
EMA	Total	20,253	565.5	488	2.41	0.86

EMA, ethnic minority area.

Qinghai, and Xinjiang, this number was below the average level of hospitals in EMAs.

In summary, under the impetus of national policies, the overall level of high-quality medical resource allocation in ethnic minority areas is rapidly improving, but overall, development is still very uneven, and the total amount of high-quality medical resources in Tibet, Ningxia and other areas is relatively lacking. There is also a large gap with relatively economically developed areas such as Guangxi and Yunnan.

3.2 Dynamic evolution analysis

3.2.1 Spatial difference analysis

We used the Dagum Gini coefficient decomposition method to measure the overall Gini coefficient, intra-regional Gini coefficient, inter-regional Gini coefficient, and contribution rate from 2007 to 2021 (see the Appendix for the results). Figure 1 depicts the trend of the Gini coefficient over the observation period, which indicates that the overall Gini coefficient in EMAs fell from 0.386 in 2007 to 0.314 in 2021, denoting an overall downward trend, with a total decline of 18.7% and an average annual decline of 1.2%. The total Gini coefficient increased from 2007 to 2011, reaching its highest value of 0.404 in 2011. The Gini coefficient revealed a downward trend after 2011. This suggests that the spatial distribution of HQMRs in EMAs tends to be rational.

Figure 1 depicts the changing trend of the Gini coefficients in the two EMAs from 2007 to 2021. The average Gini coefficients of the northwest and southwest were 0.281 and 0.362, indicating that the spatial distribution difference of HQMRs in the northwest was greater than that in the southwest. Although the Gini coefficient of the two regions had a certain fluctuation range, the overall trend was downward. Specifically, the Gini coefficients of the northwest and southwest fell from 0.359 and 0.344 in 2007 to 0.323 and 0.240 in 2021, respectively, with a total decline of 10 and 30.2%, respectively. This shows that HQMR optimisation in southwest China is better than that in northwest China.

Figure 1 presents the variation trend of the Gini coefficient differences between regions. The average Gini coefficient between the northwest and southwest was 0.404, and the difference was substantial. From the perspective of change, the regional differences between 2007 and 2021 demonstrated a narrowing trend, from 0.423 in 2007 to 0.356 in 2021, with an overall decrease of 15.8% and an average decline of 10.5%.

Figure 1 suggests that the contribution rate of each decomposition term to the overall Gini coefficient changed between 2007 and 2021. The contribution rates of intra-regional differences and super-variable density fell from 45.29 and 27.36% in 2007 to 43.39 and 22.02% in 2021, respectively. The contribution rates of intra-regional differences and super-variable density dropped from 45.29 and 27.36% in 2007 to 43.39 and 22.02% in 2021, respectively.

The contribution rate of regional differences rose significantly from 27.36% in 2007 to 34.58% in 2021. Intra-regional differences were the main source of overall differences. At the same time, with an increase in the volatility of the contribution rate of inter-regional differences, the contribution of inter-regional differences to overall differences increased.

3.2.2 Kernel density estimation

To further study the dynamic evolutionary characteristics of the HQMR configuration level, we used the software MATLAB 2021a to estimate the kernel density. Figure 2 displays the results, specifically the dynamic evolution of the overall horizontal distribution of HQMRs in EMAs during the observation period. First, from the perspective of the distribution position, the focal point of the overall curve gradually shifted to the right, indicating that the number and level of HQMRs rose gradually. Second, from the distribution pattern, the main peak height of the overall curve first increased and then declined, and the width increased slightly, denoting that the absolute difference in each province had an expanding trend. That is, the HQMR level in each province was gradually dispersed, and the number of identities deviating from the mean increased gradually. Third, from the standpoint of distribution continuity, the distribution curve of EMAs presented a "right drag" phenomenon and slight

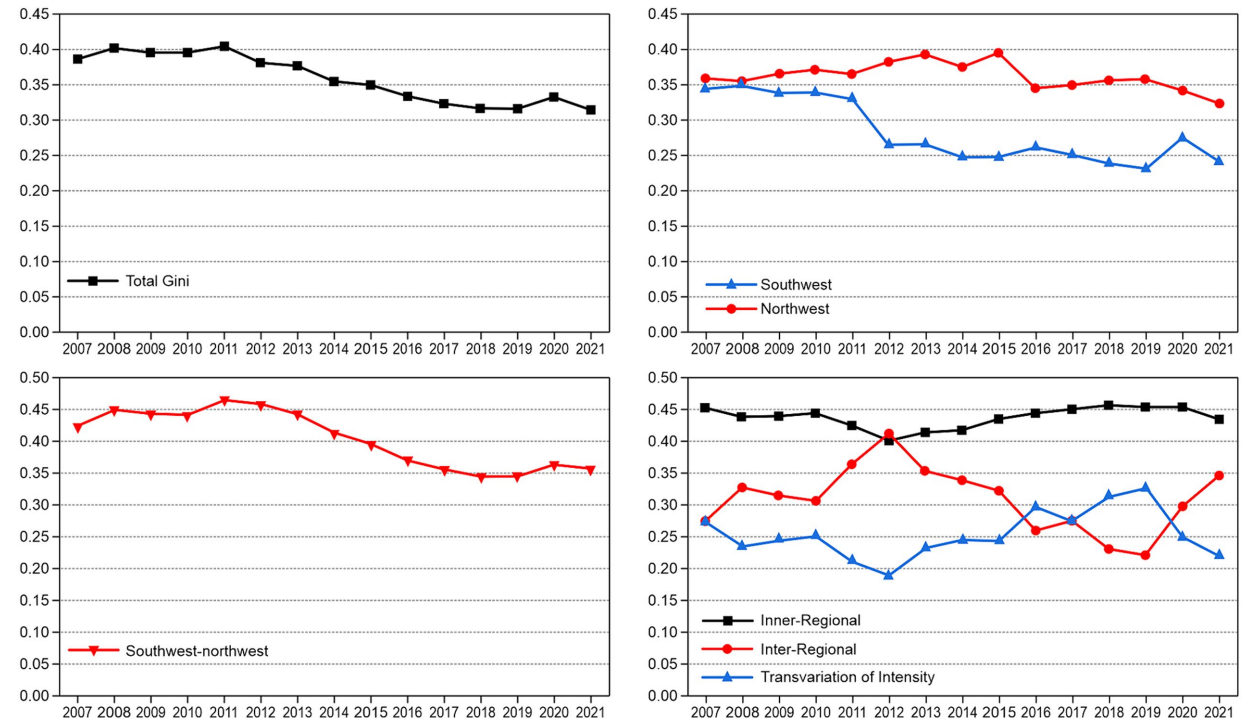


FIGURE 1
The variation and contribution rate of the HQMR level in EMAs.

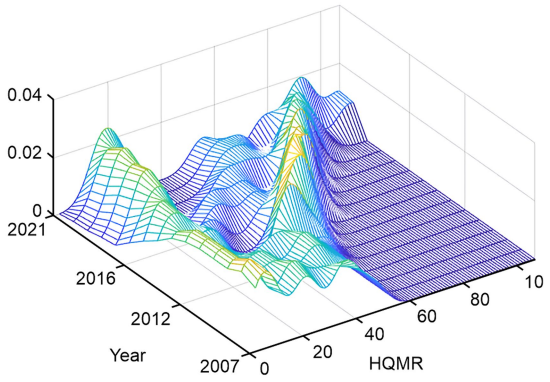


FIGURE 2
Estimate of nuclear density in EMAs.

widths, reflecting the slow widening of the gap between regional provinces, which is manifested as the gap between high-level regions (such as Yunnan and Guangxi) and low-level regions (such as Ningxia and Tibet). Finally, from the angle of differentiation, the curve as a whole changed from "unimodal" to "bimodal," suggesting that the HQMR level presents a two-stage differentiation trend; this indicates a significant gradient effect in EMAs.

3.2.3 Analysis of influencing factors of the HQMR configuration level

Given influencing factors and data types, we initially used ordinary least squares (OLS) regression and FE and RE models (in order to save space, the estimation results of OLS model, FE model and RE model are omitted). In building an OLS model, we found clear autocorrelations among the independent variables. According to previous studies, when autocorrelations exist among independent variables, GMM estimation can be adopted to solve the problem of estimation bias; however, these two methods are more suitable for short-term dynamic panels with *N*.

As seen in Table 4, the LSDVC-1 and LSDVC-2 models were generally consistent in the estimation outcomes, so we chose one of them for analysis. The system GMM has many advantages (e.g., good stability), and the estimation efficiency is higher than that of the differential GMM. Hence, we adopted the LSDVC-2 model and used

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TABLE 4 Analysis results of the LSDVC.

Variable	LSDVC-1	LSDVC-2
L1.y	0.141* (1.82)	0.182** (2.08)
X1	−2.353** (−2.24)	−2.719** (−2.09)
X2	0.0454 (0.32)	0.0256 (0.15)
X3	3.433** (2.00)	3.700* (1.93)
X4	1.331 (1.56)	1.348 (1.43)
X5	3.937*** (3.04)	4.336*** (2.75)
X6	−0.0000592*** (−3.76)	−0.0000627*** (−3.25)
X7	−0.185 (−0.35)	−0.252 (−0.40)
X8	0.0572 (0.05)	−0.0475 (0.03)
X9	−1.464*** (−5.68)	−1.551*** (−5.04)

LSDVC, least squares dummy variable coefficient; Z in brackets.
*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

the GMM estimator of the Blundell–Bond system to obtain the initial value.

When we used the HQMR level of the first order as the independent variable, according to the estimation outcomes of the LSDVC-2 model, the HQMR level of the first order had a significant, positive correlation with the HQMRs of the current year. The estimated coefficient was 2.08, which passed the significance level test of 5%. The results show that HQMRs have obvious time inertia and a significant cyclic promotion effect.

The permanent population size was X1. According to the estimation outcomes of the LSDVC-2 model, there was a significant, negative correlation between the size of the permanent population and the HQMR level; the estimated coefficient was −2.09, which passed the significance level test of 5%. This suggests that HQMRs fall with a rise in the permanent population size.

As for X3, according to the estimation outcomes of the LSDVC-2 model, there was a significant, positive correlation between the urbanization rate and the HQMR level, with an estimated coefficient of 1.93, which passed the significance level test of 10%. This shows that with an improvement in the urbanization level, the HQMR level will improve.

X5 indicates GDP and X6 GDP *per capita*. According to the estimation outcomes of the LSDVC-2 model, both of them passed the significance level test of 1%. The estimated coefficients of GDP and *per capita* GDP were 2.75 and −3.25, respectively, implying that the improvement of the economic level has two sides to the enhancement of the HQMR level; On the whole, there is a positive correlation between the two, and there is a significant negative correlation when subdivided into individual levels.

The number of students in colleges and universities was X9. According to the estimation results of the LSDVC-2 model, there was a significant, negative correlation between the number of students in colleges and universities—representing 100,000 people per higher education institution—and the HQMR level. The estimated coefficient was −5.04. This suggests that as the number of college students increases, the level of HQMR will decrease.

The HQMR allocation levels from 2007 to 2021 generally resulted from a combination of factors. Among them, GDP *per capita*, the size of the permanent resident population, and the number of students in colleges and universities had a significant inhibitory effect, while GDP and urbanization rate had a significant promoting effect.

Population density (X2), transfer payments (X3), medical and health spending (X7), and the illiteracy rate (X8) did not pass the significance level test, implying that their effects on the HQMR levels were not significant.

In this section, we perform a robustness test to ensure whether the empirical results remain unchanged. We employ difference- and system-GMM estimators developed by Arellano and Bover and Blundell and Bond to determine the robustness of our results (40, 41). We check whether both difference- and system-GMM estimators are consistent by conducting two specification tests. First, we use the Sargan test of over-identifying restrictions, which identifies the overall validity of instruments. Second, we examine whether the second-order residuals are serially correlated. As a result, we find that the *p*-value in the Sargan test is not significant, which highlights that overall instruments are valid. Additionally, we confirm that second-order serial correlation is absent. Therefore, the inferences drawn by these estimations can be used in policy decision-making.

Table 5 reports the empirical results of the model. The system GMM estimation is used as an alternative analysis method. Therefore, the system GMM estimation supports our previous results obtained by the

TABLE 5 Using alternative estimation.

Variable	Differential GMM	System GMM
L1.y	0.110* (1.78)	0.340** (2.15)
X1	−1.25 (−0.07)	1.843* (1.99)
X2	0.135 (1.15)	−0.487* (−2.82)
X3	4.48*** (3.57)	6.948*** (2.19)
X4	1.84** (2.56)	−0.116 (−0.11)
X5	4.304 (0.24)	4.081** (2.11)
X6	−4.312*** (−0.25)	−3.71* (−1.85)
X7	1.028** (2.63)	0.208 (0.23)
X8	0.0320 (0.05)	1.471 (0.51)
X9	−1.152*** (−11.08)	−1.460*** (−3.02)
Individual effects	Yes	Yes
Time effect	No	No
Constant	–	–
AR (1): *p*-value	0.002	0.021
AR (2): *p*-value	0.198	0.645
Hausman test	0.204	0.148
Observations	90	107

GMM, Gaussian mixture model; t in brackets.
*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

LSDVC method, which indicates that our empirical results are robust and constant. That is to say, the coefficients of the influencing factors affecting the HQMR level are still statistically significant and remain basically unchanged except for X1. X1 represents the permanent population size, easily Affected by slight sample deviation (31).

4 Discussion

Focusing on EMAs in China, we investigated the temporal and spatial evolutionary trend of, and regional differences in, the HQMR level from 2007 to 2021, and we explored the influencing factors of the HQMR level in EMAs based on the four elements of demographic structure, level of economic development, education level, and medical and health spending. We drew four conclusions from the study results.

First, the total amount of HQMRs in EMAs is rising rapidly, but there is still a gap between EMAs and the rest of the country. Our results suggest that in the 15 years between 2007 and 2021, the number of tertiary hospitals expanded from 175 to 488, an increase of 179%. The average number of tertiary hospitals per million people rose from 0.93 to 2.41. The average number of tertiary hospitals per 10,000 km^2 increased from 0.31 to 0.86. The growth rate of HQMRs in EMAs was significantly higher than the population growth rate, implying that the probability of residents obtaining HQMRs increased significantly (42). The results demonstrate that the Chinese government's measures have achieved remarkable outcomes in enhancing the HQMR level in EMAs. However, compared with the relatively developed areas in the eastern and central regions, the allocation level of HQMRs in EMAs is still relatively insufficient, consistent with Yuan's findings. Hence, to further realize the strategic goal of continuously improving the quality of health services and the level of health security, proposed in the *Healthy China 2023 Programme*, the government should strengthen its role in HRA, improve the feasibility of policies, reinforce relevant safeguards, ensure the implementation of pertinent policies, and increase the total amount of HQMRs in EMAs (43).

Second, we analyzed the regional differences and dynamic evolution of HQMRs in EMAs and found that the regional distribution of HQMRs tended to be reasonable; notwithstanding, the trend of the two-tier approach has become more serious.

Based on the Dagum Gini coefficient, the Gini coefficient of HQMRs in EMAs showed a downward trend during the observation

period and an overall imbalance of HQMR allocation in EMAs. Our conclusions are similar to those of past studies on HRA in China (44, 45). From the perspective of inter-regional differences, internal differences in the northwest are greater than those in the southwest. Different provinces also have clear differences in location, resource endowment, economic scale, and financial capacity. The provinces and autonomous regions in the northwest are large in size, with many neighboring provinces (such as Inner Mongolia) bordering eight provinces and Qinghai bordering four provinces; hence, there are great differences between these provinces. The geographic location of each province in southwest China is relatively concentrated—the area is small, and development is relatively concentrated in all aspects. As a result, HQMR levels are more balanced in the southwest.

Regional differences have narrowed. The differences between the northwest and southwest revealed a narrowing trend, and the differences between regions declined. This is closely related to the western development policy put in place by the government. Since 1999, China has implemented the strategy of developing the western region, formulated a series of coordinated regional development strategies for 12 provincial-level administrative regions (including EMAs), and promoted the reform of the broader medical network, thus narrowing the gap in medical care among different provinces in the west. Intra-regional variation is the main factor of overall variation. From 2007 to 2021, the contribution rate of intra-regional differences was always greater than 40%, which was the main source of regional differences. Over time, the contribution rate of super-variable density gradually decreased, and the contribution rate of inter-regional difference gradually rose, indicating that the contribution of inter-regional differences to total differences slowly increased.

There was a particular gap in the overall HQMR distribution, showing a trend of two-level differentiation. According to the results of nuclear density estimation, the HQMR level in EMAs has significantly improved, and inter-regional differences have improved overall, but the gap between high-level and lower-level provinces still exists, and the polarization trend is becoming more serious. Simultaneously, there are regions with a very high HQMR level and regions with a very low HQMR level, and it is difficult to achieve the supply balance of HQMRs in the short term. As HQMRs are an important part of medical care resources, this distribution is similar to the distribution of overall medical resources in China.

Finally, the results of influencing factors indicate that the size of the permanent resident population, urbanization rate, GDP, *per capita* GDP, and the number of students in colleges and universities are key factors affecting the HQMR level. Cities with relatively small populations and fairly concentrated HQMRs have absolute advantages in terms of the HQMR level (46). With the increase in population size, the unbalanced allocation of medical resources is exacerbated (47), negatively affecting the improvement of the HQMR level. Moreover, the urbanization rate can improve the HQMR level. Urbanization has a significant effect on economic growth, especially in developing countries (48, 49). It is widely believed that a region's economic development can provide strong support for healthcare spending, and governments in richer regions can afford to invest in HQMRs, whereas those in poorer regions cannot (50). Hence, urbanization will bring about economic growth in EMAs, thus promoting the improvement of the HQMR level. GDP and *per capita* GDP are important indicators reflecting the level of economic and social development, GDP positively promoted the HQMR level in EMAs, while *per capita* GDP had a negative inhibitory effect. On the one hand, with the increase in *per capita* GDP and the improvement of residents' living standards, the demand for medical services has unreasonably increased, resulting in a decline in the efficiency of primary medical services (51, 52). The national policy focus is tilted toward primary medical institutions, which indirectly affects the improvement of the HQMR level; however, the current constraints on health spending have been relaxed, quickly leading to wasted allocated funds and lax supervision and management. In addition, the government pays no attention to the efficiency of the use of funds, which ultimately results in the inhibition of the positive promotion effect brought by total GDP growth and the impact on the HQMR level. The impact of education level on the HQMR level has been confirmed in previous studies. We further explored the impact of higher education level on the HQMR level and found that it had a significant negative impact on the HQMR level. Past studies have found that the overall mortality rate of Chinese residents decreased with an improvement in education level (53), and people with higher education tend to have better health awareness and living habits, thereby reducing their own risk of disease. As such, with the rise in the number of students in colleges and universities and the ongoing improvement of higher education institutions, the frequency and prevalence of medical treatment for residents have been reduced to a certain extent (54), thus reducing the demand for medical services and affecting the improvement of the HQMR level.

From an international perspective, this study has value. First, we recognize that residents' health behaviors and HRA in China's EMAs may be very different from those in other regions due to ethnic culture, folk medicine, geographic location, and other reasons (55). Therefore, we focused on the distribution of HQMRs in EMAs, providing research support for alleviating health inequality in EMAs and promoting the high-quality development of medical resources. Second, compared with past studies, we used the Dagum Gini coefficient and kernel density estimation to dynamically analyze the regional differences and evolutionary trends of HQMRs, which can more clearly show the developmental context of HQMRs. Our empirical results prove that there are significant differences in HQMR levels among EMAs and that they change over time. This suggests that spatial differences should be fully considered when studying the distribution of HQMRs in the future. Finally, we explored key factors affecting the HQMR level from multiple angles and found for the first time that population size, higher education level, and *per capita* GDP had a significant inhibitory effect on the HQMR level. In the future, coordination with the population level, education level, economic growth, and other dimensions should be considered when formulating relevant policies.

This study has a few limitations as well. First, we only measured the number of HQMRs by the number of tertiary hospitals and did not consider the number of beds or medical personnel in tertiary hospitals. Second, when exploring influencing factors, we found that factors such as the level of economic development, demographic structure, and education level significantly affected the improvement of the HQMR level in EMAs. The next step would be to further investigate critical factors affecting the distribution of HQMRs in EMAs from the structural perspective. At the same time, the shrinking and expansion of HQMRs should receive attention on the demand side of medical services. Therefore, future studies should collect

demand-side data to construct a demand index and assess the spatiotemporal evolution and influencing factors of the demand for HQMRs in EMAs. Finally, due to data availability, we only discussed HQMRs at the provincial level; the situation in cities and counties requires further analysis.

5 Conclusion

We empirically examined the spatial and temporal trends in the HQMR level in EMAs and the factors influencing it based on the latest available data from official publications. This study provides insight into scientific management and guidance for policymakers to formulate effective policies for achieving higher levels of HQMR allocation. The main findings were that the overall HQMR level in EMAs is improving rapidly but is deficient in developed regions (16). Additionally, the differences in the regional distribution of HQMRs in EMAs are narrowing. However, they are still significant, and the severe polarization of resource allocation is a key issue that needs to be addressed in future research. At the same time, when formulating policies, it is necessary to take into account the need to coordinate with the level of economic development, the level of education, and the size of the population, rather than simply increasing the number of HQMRs. In summary, we recommend the following:

First of all, starting from the level of economic development, this study finds that the overall level of economic development has a significant positive impact on the allocation of high-quality medical resources, and *per capita* GDP has a negative impact on the allocation of high-quality medical resources. Therefore, the driving role of economic development in improving the allocation of high-quality medical resources should be given full play, and differentiated policies should be implemented according to different levels of economic development to achieve coordinated development of high-quality medical resources between the two subsystems. In areas with relatively good economic development, the construction of regional medical centers should be promoted, as should the development of high-tech research and development and the training of high-level health professionals, so that economic development can become a key driving force for improving the allocation of high-quality medical resources. In areas with relatively lagging economic development, the total amount of high-quality medical resources should be increased, the intensity of special intergovernmental transfer payments should be strengthened, and policies should be introduced to compensate for and introduce local social resources, enhance the government's precision intervention, and guide the allocation of regional medical resources toward rationality.

Secondly, from the perspective of education level, this study found that higher education level has a negative impact on the level of high-quality medical resource allocation. As found in the previous study, this is mainly due to the higher health literacy of highly educated people. Therefore, on the one hand, we need to further improve the supply of high-quality medical resources in line with demand, meet the diverse, multi-faceted and multi-level medical service needs of different groups of people, and promote the overall improvement of the quality of high-quality medical resources. On the other hand, we need to incorporate theoretical ideas such as prevention-oriented and proactive medical care into the development of high-quality medical resources, not only to improve the level of disease treatment and optimize the allocation of hospital resources, but also to create a high-quality and efficient full-cycle medical and health service system.

Finally, in terms of population size, we must take into account the population situation in each region of the ethnic area, not just the total amount of high-quality medical resources, but also the *per capita* distribution and accessibility of the population. Therefore, in order to improve access to high-quality medical services for all citizens, it is recommended to accelerate the expansion and balanced distribution of HQMRs and promote coordinated regional development, rather than simply increasing the number of HQMRs.

In summary, this study is the first to comprehensively analyze the current situation of the allocation of high-quality medical resources in ethnic minority areas from the perspectives of spatiotemporal dynamic evolution and allocation influencing factors, and innovatively proposes policy recommendations for promoting the level of high-quality medical resources in different dimensions. This is of great practical significance for promoting the high-quality development of the medical and health service system in ethnic minority areas, and to a certain extent, it makes up for the research gap in this field.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

BL: Data curation, Formal analysis, Writing – review & editing. LH: Investigation, Supervision, Writing – original draft. ZC: Conceptualization, Data curation, Methodology, Writing – original draft. BH: Writing – original draft, Writing – review & editing. CL: Software, Validation, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The impact of rural health insurance on vulnerability to chronic poverty among rural residents in China: analysis using Probit and IVprobit models

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Introduction: Poverty is a global problem, and combating it is a major governance issue worldwide. In China, poverty management efforts have shifted from eliminating absolute poverty to managing relative poverty. One of the most important tasks in managing relative poverty in the post-poverty reduction era is to prevent recurring poverty due to illness. Rural health insurance is an important method of preventing and mitigating disease risk and a key part of China's poverty reduction policy, including among rural residents. However, the mechanism by which basic health insurance alleviates vulnerability to poverty, the causal effect of rural health insurance on vulnerability to poverty, and differences based on having a second health insurance policy and by age and income have not been sufficiently explored. Therefore, this study examined the impact of rural health insurance on vulnerability to long-term poverty among rural residents in China. In addition, this study evaluated the impact of having a second health insurance policy and differences in the effects of rural health insurance by age and income.

Methods: This study used data from the 2014, 2016, 2018, and 2020 China Family Panel Studies. Household-related characteristics, such as finance, education, and healthcare, were retrieved from the household database; while data on healthcare expenditures, healthcare insurance, and personal-related characteristics were retrieved from the adult database. Robustness tests were conducted with Probit models, and endogeneity tests were conducted with IVprobit models.

Results: Vulnerability to poverty was significantly lower among residents with rural health insurance than those without any health insurance coverage, and this difference was observed across age and income groups. These findings were consistently robust and significant after controlling for endogeneity, considering sample selectivity, and eliminating measurement bias in the core variables.

Conclusion: The findings indicate that rural health insurance is an important tool for poverty alleviation. The current results could effectively reduce the economic vulnerability of rural households facing health risks, ensuring broader economic security. Moreover, these findings provide policy references for managing relative poverty in China.

KEYWORDS

rural health insurance, rural residents, vulnerability to poverty, China, poverty governance

1 Introduction

Poverty eradication is a long-term task for China's economic and social development. Since the reform and opening up, China has implemented a series of poverty reduction strategies and has made unprecedented achievements. By 2020, China had eliminated absolute and regional poverty.[1] However, as poverty is characterized by complexity, systemicity, and dynamic change, the problems of relative and recurring poverty, particularly due to illness, remain prevalent. Preventing recurring poverty in rural areas has become the new focus of poverty governance. Using health insurance to prevent future risks and establishing a long-term mechanism to address relative poverty are key ways to solidify the results of poverty alleviation and build a firm foundation for poverty eradication in China. Therefore, accurately assessing rural residents' vulnerability to poverty and analyzing the impact of basic health insurance on vulnerability to poverty and its internal mechanisms are important for consolidating the results of poverty eradication and promoting common prosperity in China.

Rural health insurance is an important part of the social insurance system and is a policy tool for preventing poor health and mitigating disease shocks. Since 2003, when the new rural cooperative medical care system was piloted, China has continued to develop a basic health insurance system for rural areas, with the health insurance system for urban and rural residents as its pillar, supplemented by a system of insurance for major illnesses and medical assistance. This has provided full coverage of the rural population. Since 2010, the coverage rate of rural health insurance in China has significantly increased. According to data released by the National Healthcare Security Administration of China, by 2018, the coverage rate of basic medical insurance nationwide had stabilized at over 95%, achieving almost universal coverage. For example, in 2020, the *per capita* funding for basic medical insurance for rural residents in China was 833 yuan, of which government financial subsidies were at least 550 yuan, and individual contributions amounted to 280 yuan per person per year. During the same period, the *per capita* disposable income of rural residents in China was 17,131 yuan, with health insurance expenditures accounting for about 1.63% of total income. In China, the reimbursement policy for the New Rural Cooperative Medical Insurance varies by region and by the level of medical institutions, typically with a deductible. For example, in Hunan Province (a province in central China), the deductible for hospitalization at township hospitals is 200 yuan, 500 yuan at county-level hospitals, 700 yuan at city-level hospitals, and 1,000 yuan at provincial-level hospitals. In addition to the New Rural Cooperative Medical Insurance provided by the state, rural residents may also benefit from public health insurance, urban employee medical insurance (some rural residents may work in cities), and private health insurance, among others. This study identifies groups with any two or more health insurance policies as "having secondary medical insurance." According to the descriptive statistics in Table 1, 3.9% of the sample population has secondary health insurance.

Since the 18th National Congress of the Communist Party of China, China has introduced a series of health insurance poverty alleviation initiatives from the central government to the local level. These initiatives provided systematic guarantees to lift the rural poor out of poverty (nearly 10 million households). Therefore, considering China's experience of escaping absolute poverty, the impact of rural health insurance on vulnerability to poverty must be analyzed. According to data from the Poverty Alleviation Office of the State Council of the People's Republic of China, poverty due to illness was the primary poverty-causing factor for rural residents as of 2015. People continue to face a high burden of medical expenses, especially in middle- and low-income groups, and the phenomenon of poverty caused by illness and recurring poverty due to catastrophic medical expenses occurs occasionally. One of the most important tasks in combating relative poverty in the post-poverty alleviation era is to prevent recurring poverty due to illness. Health insurance is an important method of preventing and resolving disease risks, and the effect of health insurance participation and medical treatment on poverty due to illness expenses[2] should be comprehensively examined (1).

Poverty is a common problem worldwide, including in both developed and developing countries. Scholars have examined the association between health insurance coverage, poverty, and government financial support in developed countries, such as the United States and Germany. Empirical evidence of catastrophic and poverty expenditures in Germany's dual-insurance system has been used to analyze financial risk protection in private health insurance (2–5). Some developing countries, such as Senegal, Congo, India, Pakistan, and Bangladesh, have achieved national health insurance coverage and reduced healthcare expenditures for poor people; however, inequalities in health insurance coverage have been shown (6–10). In Namibia and Ghana, reorienting public expenditure policies on healthcare and education through national health insurance schemes has improved access for the poor (11, 12). Health insurance in China is an effective measure to alleviate household poverty and inequality based on financial status. Policies should introduce comprehensive insurance systems with varied reimbursement expense rates for different groups to alleviate poverty (13–16). Scholars have also explored the link between health insurance and

1 Absolute poverty refers to a condition where individuals or households cannot obtain basic necessities like food, clothing, and shelter, typically measured by a specific poverty line. Relative poverty is based on a society's overall income level, where individuals or households have significantly lower incomes compared to the societal average, making it difficult for them to maintain a standard of living comparable to others. Regional poverty focuses on poverty within specific geographic areas, often reflecting issues caused by regional developmental imbalances or environmental factors. Poverty lines established by various countries and international organizations are based on "absolute poverty," aiming to meet the minimum survival needs.

2 Download the raw data at http://isss.pku.edu.cn/cfps/index.htm.

TABLE 1 Descriptive statistics.

Variable	Full sample (N = 48,712)		Having medical insurance (n = 45,490)		Not having medical insurance (n = 3,222)	
	Mean	SD	Mean	SD	Mean	SD
Vulnerability	0.392	0.112	0.392	0.111	0.403	0.117
Having medical insurance (Yes = 1, No = 0)	0.934	0.249	1	0	0	0
Having secondary medical insurance (Yes = 1, No = 0)	0.039	0.193	0.041	0.199	0	0.018
Sex (Male = 1, Female = 0)	0.499	0.500	0.501	0.500	0.467	0.499
Age	51.379	14.899	51.477	14.797	49.994	16.216
Family members	4.548	2.126	4.559	2.112	4.39	2.302
Years of education	5.585	4.599	5.597	4.583	5.428	4.821
Income	4.477	4.383	4.489	4.375	4.304	4.498
Net house asset	9.675	24.097	9.602	23.581	10.710	30.457
Debt	0.986	3.95	0.990	3.952	0.932	3.909

specific diseases, analyzing factors such as the community environment, racial disparities, economic policies, and cultural systems (17–20).

In China, health is a key factor in individuals' impoverishment, and health insurance can effectively counteract health shocks. Illness reduces farmers' labor efficiency, supply, and income. Medical expenditures increase farmers' economic burden. If medical expenditures exceed affordability, they can become catastrophic, causing a vicious circle of poverty and illness. Therefore, studies have examined the impact of health insurance on vulnerability to poverty. Pigou argued that the state's participation in income distribution through the social insurance system promotes income equalization and helps maximize social welfare, which provides solid theoretical support for poverty reduction through health insurance (21). Liu Yuanli was the first to propose the theory of poverty reduction through health insurance. This was supplemented and improved by Yip and Hsiao, who proposed that health insurance alleviates poverty caused by an illness by compensating for the medical burden, with the amount of compensation negatively correlated with out-of-pocket medical expenditures and positively correlated with the poverty reduction effect (22). Health insurance directly affects poverty by compensating for individual medical consumption and indirectly affects it by improving the individual's capital stock. It improves people's health and increases investment in education (23–25). Thus, health insurance effectively mitigates the impact of diseases on individual income, reduces the likelihood of individuals falling into poverty, prevents recurring poverty, and consolidates the results of poverty eradication.

Previous studies have explored poverty governance using basic health insurance. Asfaw and Jütting found that in developing regions, such as Africa, health insurance had the dual effect of increasing healthcare service use and lowering the incidence of poverty (26). Sommers and Oellerich revealed that U.S. Medicare significantly reduced medical out-of-pocket expenditures and alleviated poverty (27). Gu et al. demonstrated that health insurance improved health and alleviate poverty caused by illness among urban residents in China (28). Poverty governance in China should focus on relative poverty in the future as well as the present. Existing studies have used poverty incidence and intensity to measure poverty; however, the problems are complex. Vulnerability to poverty better reflects the risk of individual farmers falling into relative poverty in the future. Zining et al. revealed that health insurance effectively reduced vulnerability to poverty, with a more significant effect among people with poor health (29). Gao and Ding argued that the New Rural Cooperative Major Disease Insurance effectively alleviated long-term poverty in rural areas (30).

However, the mechanism by which basic health insurance alleviates vulnerability to poverty has not been fully and systematically investigated. Moreover, the causal effect of rural health insurance on rural residents' vulnerability to poverty has not been sufficiently explored. Most existing studies have chosen a single year but have not conducted tracking surveys or continuous analyses. In addition, studies have not analyzed the population with a second health insurance policy and people of different age groups, ignoring the differences and long-term dynamics of health insurance among different population groups. Therefore, this study examined vulnerability to long-term poverty among the rural population in China and explored differences based on having a second health insurance as well as by age and income. This study could help improve the health insurance policy for impoverished people in rural areas and provide an important reference for comprehensively assessing the performance of rural health insurance implementation in China.

2 Methods

2.1 Data sources

This study used data from the 2014, 2016, 2018, and 2020 China Family Panel Studies (CFPS),[3] which surveyed social,

3 Available from http://isss.pku.edu.cn/cfps/index.htm.

economic, demographic, educational, and health aspects at the individual, household, and community levels. The CFPS sample covers 25 provinces, municipalities, and autonomous regions in China, with a sample size of 16,000 households, including all household members.

This study used data of rural residents aged 25–85 years. Individuals in this age range are typically married and have health insurance; thus, the population is representative of the situation in China. First, we identified the household characteristics and personal information of the head of the household through the household and adult databases. We retained only the data of rural residents as identified in household registers. Second, we retrieved data on household-related characteristics, such as income, education, and healthcare, from the household database and data on medical expenditures, health insurance, personal characteristics, and number of households from the adult database.[4] Finally, we matched the household codes with the household head and merged the data samples, resulting in 8,652 households and 48,712 samples.

2.2 Variable selection

The explanatory variable in this study was the level of vulnerability to household poverty. Vulnerability to poverty measures the likelihood that a household will fall into poverty in the future, considering not only the current characteristics and economic situation of the household but also a combination of various risk factors that it may face in the future. Vulnerability to poverty comprised three aspects: vulnerability to expected poverty (VEP), vulnerability to low expected utility, and vulnerability to uninsured risk exposure. This study used VEP to measure vulnerability to poverty (31, 32).

This method calculates the period during which a household or individual fell into poverty based on the household or individual characteristics of that period (32, 33). This method was significantly improved by Klasen and Waibel (34). The method regresses income on observable variables and shocks to obtain an expression for future income, which assumes that the logarithm of income follows a normal distribution; thus, the probability that future income will fall below a certain value (usually the poverty line) is referred to as the vulnerability line. The calculation uses the three-stage generalized least squares estimation (feasible generalized least squares) to establish the mean income and income fluctuation model, estimate the logarithm of *per capita* income, and conduct an ordinary least squares regression analysis on the squared residuals after the regression analysis. The specific method for VEP is as the following Equations 1-5:

$$lnIncome_{it} = \alpha X_{it} + \varepsilon_i \tag{1}$$

where $\mathrm{lnIncome_{it}}$ represents the logarithm of family i income level in year t; $\times_{it}$ covers family, personal characteristics, and factors of vulnerability to risk shock; and $\mathring{a}_i$ represents the residual difference of the regression analysis. This variance is then used to estimate the uncertainty of household consumption; that is, the consumption variance of an individual or household. An estimate of this variance can be used to measure the volatility of future consumption levels. To estimate the variance of household income, the heteroscedastic structure weight is constructed as follows:

$$\varepsilon_i^2 = \beta X_{it} + \xi_i \tag{2}$$

where ε_i^2 is the estimated consumption variance for the *i* household and β is the parameter estimated from step 1.

In the second step, the weighted regression analysis of the residual square and logarithm of income is performed again:

$$E\left(lnIncome_{i,t+1}|X_{it}\right) = X_{it}\,\hat{\alpha_{FGLS}} \tag{3}$$

$$V\left(lnIncome_{i,t+1}|X_{it}\right) = \varepsilon_i^2 = X_{it}\,\hat{\beta_{FGLS}} \tag{4}$$

In the third step, VEP values are calculated by estimating the probability of each household falling into poverty. The VEP represents the probability that a family's future consumption level will be below the poverty line, which can be calculated using a standard normal distribution function. The logarithm of income is assumed to follow a normal distribution, and the poverty line and vulnerability to poverty threshold are defined, as follows:

$$\hat{VEP_{it}} = \Pr\left(lnIncome_{it} \le lnPoor\right) = \phi\left[\frac{lnPoor - X_{it}\,\hat{\alpha_{FGLS}}}{X_{it}\,\hat{\beta_{FGLS}}}\right] \tag{5}$$

The choice of the poverty line directly determines the final analytical results. In 2018, the World Bank identified survival expenditures per person per day of less than $1.9, $3.2, and $5.5 as the extreme, medium-low, and medium-high poverty lines, respectively (35). Based on the 2018 US-Chinese currency exchange rate (1:6.61), the annual poverty lines were RMB 4584, RMB 7720, and 13,270 yuan. During the same period, the poverty line set by China's Poverty Alleviation and Development Department was RMB 2855; however, according to the State Council Poverty Alleviation Office, most of China's provinces set local standards higher than the national standard, with 12 provinces setting the poverty line between RMB 4000 and 6,000. According to Zhang and Wan, a higher poverty line corresponds to a higher prediction accuracy; therefore, the medium-low poverty line standard recognized by the World Bank was chosen as the poverty line reference value for this study (36).[5]

4 Income is the amount remaining after accounting for all wages, bonuses, cash benefits, and in-kind subsidies, after taxes have been deducted. Home equity is the net value of a house after subtracting housing-related debts from its market value. We chose this variable because 80% of Chinese residents' assets are in housing, with an even higher proportion among rural residents.

5 To ensure the reliability of the results, we selected the annual average exchange rates of RMB and USD for 2014, 2016, 2018, and 2020 to discount the poverty line.

The core explanatory variable used in this study was having at least one health insurance policy, expressed as $Medical\ insur_{it}$.[6] If the respondent had at least one health insurance policy, the explanatory variable $Medical\ insur_{it}$ was 1, and 0 otherwise. This indicator was identified in the CFPS database and transformed in terms of specific insurance types. Moreover, we examined having a second health insurance policy as the core explanatory variable.

The other control variables were household information, including age, sex, education level, total household income and expenditure in the past 12 months, and medical expenditure of the head of the household; asset and liability indicators, including annual household income, value of the household's net property, value of productive fixed assets, value of the household's holdings of financial products, and level of debt; and individual characteristics, including sex, age, marital status, and health. Table 1 presents the descriptive statistics of this study.

2.3 Empirical methods

We used the following model to explore the causal effect of health insurance on vulnerability to poverty:

$$Vul_{it} = \beta_0 + \beta_1 Medical\ insur_{it} + \beta_i X_{it} + \lambda_i + \eta_t + e_{it} \quad (6)$$

where Vul_{it} represents household vulnerability to poverty measured under the \$3.2/person/day poverty standard; $Medical\ insur_{it}$ represents whether sample i had at least one health insurance in year t; β_1 is the core regression coefficient; X_{it} represents the control variable; λ_i represents the regional fixed effect; η_t represents the fixed effect of time (year); and e_{it} represents the residual term.

Further, we used a Probit model to estimate Equation 6. The results were used as a robustness test, in which three poverty line probabilities were chosen simultaneously. The first vulnerability to poverty line was 29%; that is, a household was considered vulnerable if its future probability of falling into poverty exceeded 29% (33). The second vulnerability to poverty line was 40%, following Rajadel (37). The third vulnerability to poverty line was 49%, following Chaudhuri et al. (33). If $Vul_{it} \geq Poverty\ vulnerability\ line$, household vulnerability to poverty was high, and $Vul_{it} = 1$ in the Probit model; otherwise, $Vul_{it} = 0$.

3 Results and discussion

3.1 Benchmark regression analysis results

Table 2 presents the regression analyses results for vulnerability to poverty based on rural health insurance for the entire sample, including the results using two-way fixed effects and the first vulnerability to poverty line of the Probit model. We controlled for year and province fixed effects and included control variables at the household and head of household levels. The resulting coefficients were all negative and highly significant, indicating that vulnerability to poverty among residents with rural health insurance was significantly lower than among those without any health insurance. Specifically, having health insurance reduced the vulnerability of households by 1.3–1.7% on average.

Moreover, we used the Probit model as a comparison and achieved negative and significant results. The Probit model is suitable for regression analyses dealing with dichotomous dependent variables. Although its coefficients cannot be directly interpreted in terms of economic significance, their direction and significance provide important validation. The results of the Probit model demonstrated that rural health insurance had a significant negative effect on vulnerability to poverty, supporting the findings of the fixed-effects model.

Rural health insurance significantly reduced households' vulnerability to poverty, even after controlling for year- and area-fixed effects, and when head of the household and household-level control variables were included. Robustness tests further confirmed the reliability of this finding through Probit modeling. These results revealed the important role of rural health insurance in alleviating poverty.

Moreover, households headed by men and those with higher levels of education had relatively lower vulnerability to poverty. This trend was negatively affected by the age of the head of household and increase in household size (i.e., higher probability of recurring poverty). From the household perspective, growth in income and assets helped reduce vulnerability to poverty, whereas increases in household debt were detrimental to the decline in vulnerability to poverty, which was consistent with conventional expectations.

3.2 Robustness test results

3.2.1 Endogeneity test

Endogeneity between health insurance and vulnerability to poverty could not be ruled out. The risk of endogeneity arose from omitted variables and bidirectional causal effects. As we could not observe the full range of intra-household characteristics, factors such as social networks and cultural differences may have affected the vulnerability of households to poverty. This could be handled by controlling for the fixed effects for each household; however, such an approach would lose degrees of freedom, and the data in this study did not support this approach. Second, poverty may constrain households from investing in health insurance, while simultaneously increasing the risk of poverty due to limitations in wealth levels. This bidirectional causality can complicate the relationship between health insurance expenditure and vulnerability to poverty, hindering the accurate identification of the causal relationship between the two. Therefore, we selected a two-stage instrumental variable approach to test the potential risk.

The instrumental variable of whether to purchase health insurance was household medical expenditure in the past 12 months. This instrumental variable satisfied the correlation requirement, as a higher level of medical expenditure in the previous year may stimulate the household to emphasize health insurance. This crisis effect may stimulate the household's demand for insurance to avoid medical expenditure. Medical expenditures due to illnesses in general

6 The CFPS database includes public, urban workers', urban residents', and new rural cooperative health insurance types.

households are often difficult to advance because illnesses are usually episodic and sudden; thus, medical expenditures satisfied the exogeneity requirement of the instrumental variable. We used the two-stage least squares (2SLS) and IVprobit models for endogeneity testing, and the results are shown in Table 3.

The results of the 2SLS instrumental variables test revealed that the *F*-values of the first stage were above the threshold of 10.28 without and after controlling for the individual and household control variables, demonstrating the reliability of the instrumental variables (38). Based on the regression coefficients in the second stage, the effect of health insurance on reducing vulnerability to poverty remained negatively significant. The absolute value of the coefficients was larger than the results of the baseline regression analysis, indicating that the results of the baseline regression analysis underestimated the potential effect of health insurance on reducing vulnerability to poverty after excluding endogenous risks. For robustness considerations, we validated the results of the two-stage Probit model. Although the IVprobit model could not provide the *F*-value of the first stage, the results indicated the reliability of the instrumental variables. The regression analysis

TABLE 2 The impact of rural health insurance on vulnerability to poverty.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Vul	Vul	Vul	Vul	Vep1	Vep1
Medical insurance	−0.0101***	−0.0162***	−0.0169***	−0.0130***	−0.1967***	−0.1799***
	(0.0020)	(0.0019)	(0.0019)	(0.0018)	(0.0245)	(0.0254)
Sex			−0.0127***	−0.0136***		−0.1433***
			(0.0010)	(0.0009)		(0.0128)
Age			0.0009***	0.0007***		0.0093***
			(0.0000)	(0.0000)		(0.0005)
Family members			0.0045***	0.0067***		0.0965***
			(0.0002)	(0.0002)		(0.0033)
Education			−0.0028***	−0.0022***		−0.0272***
			(0.0001)	(0.0001)		(0.0016)
*ln*Income				−0.0083***		−0.1258***
				(0.0002)		(0.0039)
*ln*Net house asset				−0.0039***		−0.0457***
				(0.0002)		(0.0024)
*ln*Debt				0.0040***		0.0352***
				(0.0001)		(0.0015)
Province FE	No	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
N	48,712	48,712	48,712	48,712	48,712	48,712
R^2	0.062	0.128	0.174	0.227	-	-

Numbers in parentheses are estimated standard errors. ***$p < 0.01$. Vul, vulnerability; VEP, vulnerability to expected poverty; FE, fixed effects.

TABLE 3 Endogeneity test.

	(1)	(2)	(3)	(4)
Variables	Vul	Vul	Vep1	Vep1
Medical insurance	−3.4938**	−4.4548*	−4.0520***	−4.0618***
	(1.6699)	(2.5438)	(0.0153)	(0.0133)
Individual control variable	No	Yes	No	Yes
Family control variable	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
N	48,712	48,712	48,712	48,712
F	16.38	14.41	-	-

Numbers in parentheses are estimated standard errors. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Vul, vulnerability; VEP, vulnerability to expected poverty; FE, fixed effects.

results indicated that the current results were robust under the low poverty line criterion.

3.2.2 Excluding measurement bias in core variables

Considering the measure of vulnerability to poverty of the explanatory variables, the empirical findings may be affected by differences in poverty line criteria. Using the definitions in Subsection 2.3, we simultaneously selected three poverty lines for robustness testing. The results are presented in Table 4.

The results demonstrated that the regression coefficients for health insurance were significantly negative regardless of which standard poverty line was chosen and whether control variables were added, indicating that the main conclusions held after excluding measurement bias in the explanatory variables. Based on the regression coefficients, when the standard of vulnerability to poverty was continuously raised, the impact of health insurance on the vulnerability to poverty of rural residents appeared to gradually increase (the absolute value of the coefficients is increasing). This suggests that under the premise of continuously raising the standard of poverty alleviation, health insurance effectively alleviates the economic burden of rural residents in the face of illness and prevents poverty from occurring or recurring owing to illness.

3.2.3 Robustness test using propensity score matching methodology

This study adopted the propensity score matching method to test the robustness of the impact of health insurance on rural residents' vulnerability to poverty. We divided the sample into a disposition group with at least one health insurance and control group with no health insurance. We adopted the propensity score matching method to estimate whether rural residents chose to invest in health insurance, and measured the sample match between the disposition group and the control group using the 1:1 proximity matching method. We obtained 2,957 pairs of samples and used Model 6 to verify whether the group with health insurance had a lower vulnerability to poverty than the group without any health insurance. The results of the regression analysis are presented in Table 5.

We included individual and household control variables; the regression analysis results of health insurance were consistently negative and significant, and the coefficients did not change significantly. We used three poverty standards; the regression analysis results of health insurance remained negative and significant, and the coefficients in absolute value increased with the increase in the standard of the poverty line. Based on the above validation sets, we concluded that the benchmark regression analysis results in this study were robust.

TABLE 4 Robustness tests for different vulnerability to poverty lines.

	(1)	(2)	(3)	(4)	(5)	(6)
	Vep1	Vep 1	Vep 2	Vep 2	Vep 3	Vep 3
Medical insurance	−0.1967***	−0.1799***	−0.2357***	−0.2095***	−0.2561***	−0.2222***
	(0.0245)	(0.0254)	(0.0245)	(0.0255)	(0.0270)	(0.0279)
Individual control variable	No	Yes	No	Yes	No	Yes
Family control variable	No	Yes	No	Yes	No	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
N	48,712	48,712	48,712	48,712	48,712	48,712

Numbers in parentheses are estimated standard errors. ***$p < 0.01$. VEP, vulnerability to expected poverty; FE, fixed effects.

TABLE 5 Robustness test using propensity score matching.

	(1)	(2)	(3)	(4)	(5)	(6)
	Vul	Vul	Vul	Vep1	Vep2	Vep3
Medical insurance	−0.0108***	−0.0108***	−0.0084***	−0.1001***	−0.1128***	−0.1275***
	(0.0029)	(0.0028)	(0.0027)	(0.0364)	(0.0367)	(0.0417)
Individual control variable	No	Yes	Yes	Yes	Yes	Yes
Family control variable	No	No	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
N	5,914	5,914	5,914	5,914	5,914	5,914
R^2	0.109	0.153	0.209	–	–	–

Numbers in parentheses are estimated standard errors. ***$p < 0.01$. Vul, vulnerability; VEP, vulnerability to expected poverty; FE, fixed effects.

3.3 Impact of second health insurance on vulnerability to poverty

To further explore the impact of health insurance on rural residents' vulnerability, we retrieved data on whether respondents had a second health insurance policy. We used the same measure as the first health insurance policy but excluded duplicate samples with two policies of the same type. We estimated regression analyses for samples of different ages using 10 years as the age threshold (i.e., six stages using 10-year intervals for those aged 25–85 years). The results are shown in Table 6.

For younger (35–54-years-old) and older (65–74-years-old) respondents, the effect of health insurance on reducing their vulnerability to poverty was the most significant. For the oldest respondents (75–85-years-old), the effect of health insurance on reducing vulnerability to poverty was low. For middle-aged respondents (55–64-years-old), the effect of health insurance on vulnerability to poverty was not significant. Younger people are in a period of high household financial burden and usually face expenses, such as raising children and paying mortgages. Health insurance reduces the burden of medical expenditures, helping them avoid financial hardships when facing health problems. In addition, this age group is often a major participant in the labor market, and health insurance coverage reduces the risk of poverty by helping them stay healthy and reducing the loss of income due to illness. Conversely, people aged 65–74 years gradually enter retirement, with fixed income such as pensions becoming the main source of income. The relative burden of medical expenditures is heavier, and health insurance can effectively alleviate this pressure. Further, the health risk of this age group increases significantly, and the protection provided by health insurance can significantly reduce financial pressure when they fall ill and help them avoid financial difficulties caused by high medical expenses.

Older individuals generally have higher healthcare needs and expenditures, and their out-of-pocket expenses are large despite having health insurance, resulting in a small effect of insurance on poverty reduction. In addition, this age group may have already accumulated wealth or may enjoy other forms of social security, and the marginal role of health insurance in the overall economic security is relatively small. Middle-aged individuals are generally working, have a relatively stable source of income, and are more tolerant of healthcare expenditures. Compared with other groups, they may have more savings and assets, and the protective effect of health insurance is relatively small. In addition, this age group may actively invest in their health before retirement and may have lower medical needs and expenditures, making the impact of insurance less significant.

3.4 The impact of health insurance on vulnerability to long-term poverty among rural residents

Moreover, we examined the relationship between age and vulnerability to poverty and visually presented the coefficient changes (Figure 1). Significant differences in health insurance were observed among individuals with one policy by age, which is consistent with the results presented above. For individuals younger than 54 years or older than 78 years, health insurance was effective in reducing the vulnerability to poverty. However, for participants aged 55–78 years may face a financial burden due to healthcare insurance investments, potentially leading them back into poverty. Therefore, we believe that the government should provide more targeted healthcare subsidies rather than applying a uniform approach to all age groups.

Among individuals with a second health insurance policy, health insurance effectively reduced vulnerability to poverty regardless of age. This finding may be closely related to the affluence and health management awareness of the segment itself. Typically, only affluent groups have the ability and willingness to invest in secondary health insurance policies. Households with higher financial strength can spend more on insurance, which provides more comprehensive healthcare coverage and reduces the financial pressure caused by unexpected medical events. The resource advantages of wealthier households help them afford healthcare expenditures, which significantly reduces their vulnerability to poverty. Groups that invest in a second health insurance policy usually have higher awareness of health management. These groups focus on prevention and timely treatment, reducing the probability of serious illnesses and corresponding high medical costs. Such proactive health management behaviors not only help maintain good health but also avoid financial difficulties caused by health problems.

TABLE 6 Impact of second health insurance.

Age (years)	(1)	(2)	(3)	(4)	(5)
	35–44	45–54	55–64	65–74	75–85
	Vul	Vul	Vul	Vul	Vul
Secondary medical insurance	−0.0126*	−0.0161**	0.0025	−0.0219***	−0.0108*
	(0.0074)	(0.0070)	(0.0062)	(0.0052)	(0.0057)
Individual control variable	Yes	Yes	Yes	Yes	Yes
Family control variable	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
N	48,712	48,712	48,712	48,712	48,712
R^2	0.173	0.173	0.172	0.173	0.173

Numbers in parentheses are estimated standard errors. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Vul, vulnerability; FE, fixed effects.

3.5 Heterogeneity tests

3.5.1 Heterogeneity analysis using wealth quartiles

Using the income quartile variables provided on the official website of the CFPS, this study examined the population heterogeneity of income classes. The regression analysis results are presented in Table 7.

Although health insurance helped reduce vulnerability to poverty for the poorest 25% of the population, its effect was not significant. This may be because people in this income bracket have extremely weak economic foundations, making it challenging to cope with the financial pressures of medical costs, even if they have health insurance. In addition, the poorest groups may have access to other forms of social security and assistance provided by the government, thereby limiting the marginal effect of health insurance.

Contrastingly, health insurance significantly reduced vulnerability to poverty for the bottom 25–50% of income earners. This group is in a more precarious economic situation but has an income base that allows them to pay for health insurance. Health insurance provides important financial protection against high medical costs associated with illness, which can lead to financial hardship. Moreover, this group may not receive additional government assistance available to the poorest groups, causing the role of health insurance to be particularly critical.

For the more affluent group (top 25–50% of income), the role of health insurance was not significant. This group has higher incomes and savings and can pay for healthcare; thus, health insurance has relatively little impact on their financial situation. The economic security of this group is relatively solid; therefore, the marginal benefits of health insurance are low. For the wealthiest group (top 25% of income), health insurance did not significantly affect vulnerability to poverty. The wealthiest households typically have sufficient financial resources and diversified sources of income to remain economically stable, even when faced with medical expenses. For these households, health insurance is a risk-management tool rather than a tool necessary for financial security.

3.5.2 Heterogeneity analysis using self-health orientation

Further, we conducted a heterogeneity analysis using respondents' self-health orientation. The results are presented in Table 8. Using the data in the CFPS database, we divided self-health orientation into five categories: unhealthy, generally healthy, relatively healthy, healthy, and very healthy.

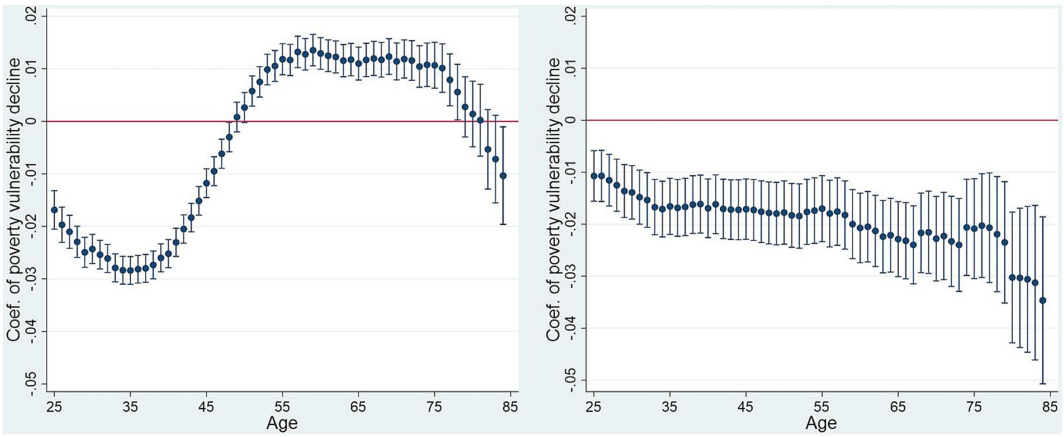


FIGURE 1
The impact of health insurance on vulnerability to poverty among different age groups.

TABLE 7 Heterogeneity analysis using wealth quartile.

	(1)	(2)	(3)	(4)
	Vul	Vul	Vul	Vul
Medical insurance	−0.0107***	−0.0161***	−0.0099**	−0.0099
	(0.0024)	(0.0032)	(0.0044)	(0.0065)
Individual control variable	Yes	Yes	Yes	Yes
Family control variable	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
n	17,268	15,111	10,413	5,264
R^2	0.203	0.229	0.226	0.163

Numbers in parentheses are estimated standard errors. **$p < 0.05$, ***$p < 0.01$. Vul, vulnerability; FE, fixed effects.

TABLE 8 Heterogeneity analysis based on self-health positioning.

	(1)	(2)	(3)	(4)	(5)
	Vul	Vul	Vul	Vul	Vul
Medical insurance	−0.0117***	−0.0227***	−0.0136***	−0.0035	−0.0106**
	(0.0036)	(0.0048)	(0.0033)	(0.0044)	(0.0046)
Individual control variable	Yes	Yes	Yes	Yes	Yes
Family control variable	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
n	10,423	7,272	16,854	7,781	6,376
R^2	0.206	0.233	0.223	0.252	0.266

Numbers in parentheses are estimated standard errors. **$p < 0.05$, ***$p < 0.01$. Vul, vulnerability; FE, fixed effects.

The results revealed variability in the impact of health insurance based on self-perceived health orientation. The effect of health insurance on vulnerability to poverty was the most significant for respondents with poor self-perceived health. This may be due to their exposure to potential health risks, with health insurance providing timely and effective medical coverage to avoid financial difficulties caused by health problems, thereby reducing vulnerability to poverty.

In addition, health insurance significantly reduced vulnerability to poverty in both unhealthy and relatively healthy groups. For the unhealthy group, the role of health insurance may be more direct and obvious, effectively reducing the economic pressure caused by medical expenses. For the healthier group, health insurance played an important role in protecting against unexpected health problems and resulting economic risks.

Contrastingly, the impact of health insurance was not significant in the very healthy group. This may be because these respondents were in better health and faced lower health risks compared to the other groups; therefore, the impact of health insurance on their economic stability was limited. In addition, this group may prefer to rely on their own health management and preventive measures and have a relatively low need for health insurance.

4 Conclusion

Eradicating extreme poverty and preventing recurring poverty among rural households have been the focus of the Chinese Government's poverty management efforts over the past two decades. Vulnerability to poverty is a typical characteristic of relative poverty and an important indicator of whether rural residents are likely to experience recurring poverty. Rural residents with at least one health insurance policy had a lower vulnerability to poverty than those without any health insurance coverage. Our findings indicated that health insurance coverage reduced vulnerability to poverty among rural residents in China. Our study contributes to the emerging literature on this topic by providing comprehensive nationwide empirical evidence and examining differences in the effect of health insurance based on having a second health insurance policy and by age and income. Our results directly inform estimates of the long-term effects of health insurance subsidies and social policies for rural residents.

We could not precisely determine the exact channel through which vulnerability to poverty was reduced. Owing to the episodic and unpredictable nature of healthcare expenditures, investing in health insurance may increase short-term financial burdens. However, health insurance can provide an important economic safety net that mitigates potential healthcare spending risks in the long term. Thus, even if some households do not receive direct health insurance benefits in the short term, they benefit because health insurance reduces their financial risk when faced with major medical expenses. In addition, health insurance may influence households' health behaviors and healthcare consumption habits, promoting a focus on preventive care, thus reducing future healthcare expenditures.

This study makes several contributions. First, this study adopted the most comprehensive and up-to-date micro-survey data to identify the causal relationship between rural health insurance and vulnerability to poverty. This study used the entire period of health insurance implementation and continuous tracking surveys, providing the latest empirical evidence for the comprehensive consolidation of the results of the poverty elimination policy. This study provided a scientific basis for preventing recurring poverty among rural residents. By comprehensively analyzing microdata, this study identified the mechanism of health insurance in various contexts, providing policymakers with powerful decision support. Further, this study focused on rural residents and examined the dynamic impact of having a second health insurance policy and the differences by age and income. This study broadened research on vulnerability to poverty and lengthened the assessment chain of health insurance. In addition, this study analyzed the long-term impact of rural health insurance on the economic stability of rural residents. By analyzing long-term data, this study revealed not only direct short-term effect of health insurance but also its indirect long-term effects. This provides an empirical basis for improving rural health insurance promotion and subsidy policies and could help policymakers design and implement targeted measures to improve the coverage and effectiveness of policies.

The significance of this study is threefold. First, it highlights the rural–urban disparity in health insurance—with 56% of the global rural population lacking coverage, which is much higher than the 22% in urban areas. The current study provides a case study for preventing rural residents in China from falling back into poverty owing to medical problems, and it provides policy references and empirical evidence for other countries to use for poverty reduction.

Second, since 2023, the Chinese government has benefited more than 180 million rural low-income people seeking medical treatment by reducing the burden of medical costs by 188.35 billion yuan. Finally, this study can promote social equity by safeguarding rural residents' medical rights and improving the quality of the medical service system, contributing to balanced socio-economic development.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: http://isss.pku.edu.cn/cfps/index.htm.

Author contributions

MZ: Writing – original draft, Methodology. MW: Writing – review & editing, Conceptualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Can China's national comprehensive medical reform increase medical resources and reduce healthcare burden: evidence from Chinese provinces

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Objectives: China's national comprehensive medical reform (NCMR) is an important attempt in the reform of healthcare system, and quantitative evaluation of its effect is of great significance for continuously deepening medical reform, grasping the reform direction, and building a healthy China. Therefore, focusing on medical resources and medical burden, this study aims to systematically explore the policy effectiveness and the provincial heterogeneity of NCMR, as well as the potential influencing factors.

Methods: Utilizing the collected multi-period panel data of 31 provinces in mainland China in 2006–2021, we regarded the release of the two batches of pilot provinces in NCMR as a quasi-natural experiment and comprehensively adopted a Staggered difference-in-differences (DID) model and Synthetic Control Method (SCM), combined with word frequency statistics and grouping regression analysis.

Results: NCMR can effectively increase the number of licensed physicians by 12.6% and reduce the *per capita* medical expense for in-patients by 7.2% in the pilot provinces. Furthermore, the NCMR policy effect in different pilot provinces shows various characteristics, and only Jiangsu, Zhejiang, and Chongqing achieve both the growth of medical resources and the reduction of medical expenditure. Meanwhile, word frequency statistics are conducted based on related policy descriptions and news reports on the official websites, so as to summarize the specific policy means in the three provinces, and provide a reference for other provinces to practice the healthcare reforms. Besides, extensibility analysis shows that the effect of NCMR is affected by the population aging and health status. Groups with low degree of population aging (low-AG)/high population health status (high-HE) performed a more obvious reform effect.

Conclusion: This study provides beneficial policy implications for increasing medical resources, reducing medical burden, and promoting medical reform process.

KEYWORDS

national comprehensive medical reform (NCMR), medical resources, residents' medical expenses, staggered difference-in-differences (DID), synthetic control method (SCM), provincial heterogeneity

1 Introduction

As a private economic product with significant social welfare implications, the healthcare system is highly complex, requiring a balance between equity and efficiency for its development (1). Additionally, the provision of health services involves multiple tasks, often leading to conflicts (2). Furthermore, information asymmetry and positive externalities are inherent challenges (3). Consequently, motivating healthcare system reform remains both a global phenomenon and a persistent worldwide challenge.

As the largest developing country, China has experienced an economic development miracle since its reform and opening-up, significantly improving the health of its citizens. However, the development of the healthcare system has lagged behind (4), with the supply of public medical resources struggling to meet the growing demand for high-quality healthcare services (5). In response, China initiated healthcare system reforms. These efforts began in the 1980s and entered a phase of adjustment and innovation in 2006. Unfortunately, these early reforms failed to effectively reduce the social burden of medical care and produced no significant improvements. In 2009, China launched a new round of reforms, known as the New Healthcare Reform, which prioritized equity and aimed to provide basic healthcare of reasonable quality with adequate risk protection for all citizens (6). The New Healthcare Reform made significant progress in three key areas: medical insurance, drug pricing, and public hospitals (7), and essentially established the framework for comprehensive healthcare system reform.

With the continued implementation of the New Healthcare Reform, the complexity and unique characteristics of the healthcare system became more evident. Conflicts between supply and demand, doctors and patients, and urban and rural areas intensified, and resource allocation remained inefficient (8). Consequently, issues related to the accessibility and affordability of medical services persisted, commonly referred to in Chinese as "kan-bing-nan" and "kan-bing-gui."

In the Chinese context, "kan-bing-nan" refers to "difficulties in accessing medical treatment," underscoring the challenge of healthcare accessibility. Specifically, the insufficient supply and uneven distribution of medical resources fail to meet the growing demand for services. Furthermore, the difficulty in implementing a primary-level first-diagnosis system contributes to the inefficient allocation of high-quality healthcare resources.

On the other hand, "kan-bing-gui" denotes the "high cost of medical treatment," focusing on the issue of healthcare affordability. Due to restrictions on the pricing of diagnostic and treatment services, the practice of using pharmacy profits to subsidize medical services has become widespread. Additionally, the parallel, multi-track medical insurance system has fragmented the mutual aid capacity of insurance, while differing health insurance financing mechanisms have widened disparities in *per capita* funding.

To consolidate reform achievements and innovate new approaches, the Leading Group for Medical Reform of the State Council of the People's Republic of China decided to pilot the National Comprehensive Medical Reform (NCMR). Two batches of pilot provinces were selected, the first in January 2015 and the second in May 2016. The first batch included Jiangsu, Anhui, Fujian, and Qinghai provinces, while the second consisted of Shanghai, Zhejiang, Hunan, Chongqing, Sichuan, Shaanxi, and Ningxia.

Specifically, to improve accessibility of medical resources and affordability of medical services, the NCMR implemented various reform measures and achieved significant results. On the one hand, regarding improved accessibility, the pilot provinces continued to optimize the allocation of medical resources and established a system of tiered diagnosis and treatment (9). Key initiatives, such as the signing of family doctors, the provision of telemedicine services, and the development of an integrated healthcare system, facilitated the distribution of high-quality medical resources to lower levels, allowing common and chronic diseases to be treated promptly in primary healthcare institutions. Additionally, online services like appointment booking, test result inquiries, and mobile payment options have greatly enhanced the convenience of seeking medical care for residents.

On the other hand, to reduce medical expenses, the NCMR used drug reform as a critical entry point, lowering inflated drug prices through centralized bidding and procurement processes. Moreover, Medicare coverage was expanded, while personal out-of-pocket expenses were reduced (10). In some pilot provinces, the role of Medicare security was further strengthened by increasing the reimbursement rate for hospitalization costs for serious illnesses among the poor to 90%.

Overall, the NCMR focused on addressing the issues of "kan-bing-nan" and "kan-bing-gui," and successfully implemented a series of reform measures in 11 pilot provinces, all aimed at resolving healthcare challenges. But what are the real-world effects of the NCMR? Has it effectively improved access to medical resources and the affordability of medical services? Are there differences in the policy impacts and specific strategies among the various pilot provinces? Are there other influencing factors at play?

To address these questions, this paper treats the introduction of the two batches of pilot provinces under the NCMR as a quasi-natural experiment and employs a staggered difference-in-differences (DID) model to empirically analyze the average policy effect of NCMR on accessibility and affordability. Additionally, the Synthetic Control Method (SCM) is used to evaluate the policy effectiveness in each pilot province individually and to explore the heterogeneity between provinces. Furthermore, the impact of population aging and regional health status on policy effectiveness is also investigated. The detailed research perspectives and empirical strategies are illustrated in Figure 1.

The marginal contribution of this study lies in two key areas. First, it focuses on the policy implications of the NCMR by addressing the practical issues of "kan-bing-nan" and "kan-bing-gui." By integrating the accessibility of medical resources with the affordability of medical services, we provide a comprehensive and systematic evaluation of the NCMR's policy effects. Second, using multi-period panel data from 31 provinces in mainland China (excluding Hong Kong, Macao, and Taiwan) from 2006 to 2021, we employ both the Staggered DID model and the SCM to scientifically assess the overall policy impact of the NCMR. This approach also allows for province-specific evaluations, exploring provincial heterogeneity and other influencing factors. These contributions aim to help policymakers better understand the successes and limitations of healthcare reform.

2 Literature review

Addressing the availability of medical resources and the affordability of medical services is not only a key objective of

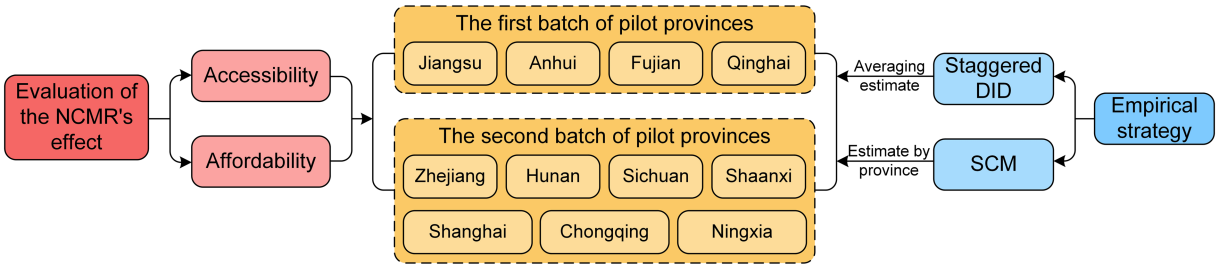


FIGURE 1
Research perspective and empirical strategies. NCMR, national comprehensive medical reform; DID, difference-in-differences; SCM, synthetic control method.

healthcare reform but also an effective means of improving public well-being. As a result, many studies have focused on the factors influencing medical resource supply and residents' medical expenditures.

In terms of resource supply, a strong correlation has been observed between regional economic development and the abundance of medical resources (11). Similarly, factors such as government health expenditure, population size, and the number of medical schools play significant roles in determining the distribution of high-quality medical resources (12). Lu et al. (13) examined the impact of referral reforms on resource accessibility, concluding that while the referral system improved access to public hospitals, it also exacerbated healthcare resource disparities between townships and urban districts.

Regarding residents' medical expenditures, environmental degradation has been shown to increase public health spending, subsequently raising individual medical costs (14). Additionally, pollution-intensive industrial clusters have been found to increase urban residents' healthcare expenses (15). Conversely, the large-scale development of digital infrastructure can enhance healthcare efficiency, thereby reducing individual medical burdens and helping to narrow wealth disparities (16).

In evaluating healthcare system reforms, much of the existing literature has focused on their impact on the demand for medical resources and the supply of healthcare services, often reflected in residents' medical expenditures and the income structure of hospitals. Baji et al. (17) used Kakwani indexes to assess the progressivity of household healthcare expenditures in Hungary before, during, and after healthcare reforms, finding that informal payments became less regressive during the reform period. They concluded that equity in healthcare financing could be improved by eliminating informal payments while increasing co-payments (17).

Similarly, Limwattananon et al. (18) evaluated the effects of Thailand's healthcare reforms on out-of-pocket healthcare expenditures using a DID model, revealing an average reduction of 28% in out-of-pocket spending, accompanied by increased utilization of inpatient and outpatient services. Zhu et al. (19) also employed the DID method to show that while drug expenditures decreased in Chinese public hospitals, spending on medical care increased due to price changes. Liu et al. (20) noted that two rounds of comprehensive public hospital reforms in Beijing contributed to lowering direct medical payments for in-patients with coronary heart disease.

In terms of hospital income structure, data from Beijing's public hospital reforms showed that the proportion of revenue from drug sales significantly declined, while some outpatients were successfully transferred from tertiary hospitals to primary healthcare institutions, such as community health centers. However, the use of CT and MRI increased unexpectedly (21). Another study demonstrated a reduction in the proportion of revenue from drug sales and medical consumables, alongside a rise in revenue from medical consulting services. This research concluded that the comprehensive public hospital reforms effectively curbed medical expenditures and optimized hospital income structures (22).

The above analyses show that while previous studies have thoroughly examined healthcare reform policies and their impacts across various countries and regions, the NCMR in China has not been fully explored. Most related research has focused on specific provinces or cities, using limited evaluation metrics and lacking a systematic, multi-dimensional assessment across all pilot provinces. Additionally, most studies relied on average effect estimations, with little investigation into the provincial heterogeneity of policy outcomes.

To address these gaps, this paper employs both the Staggered DID model and the SCM to evaluate the NCMR from two key dimensions: resource accessibility and price affordability. It also explores influencing factors, providing a valuable addition to the existing literature and offering a more comprehensive and accurate understanding of the policy's strengths and weaknesses.

3 Materials and methods

3.1 Variables and data sources

Addressing the difficulties of "kan-bing-nan" and "kan-bing-gui" is the primary objective of China's NCMR. Therefore, we evaluated the policy's effectiveness from two key dimensions: the accessibility of medical resources and the affordability of medical services.

Based on data availability and relevant studies (23, 24), we selected three indicators to measure accessibility: the number of licensed physicians (*Doctor*), registered nurses (*Nurse*), and sickbeds in medical institutions (*Sickbed*) per 1,000 population. For evaluating the affordability of medical services, we chose two indicators representing residents' medical costs: *per capita* medical expenses for outpatients (*Out-patient*) and *per capita* medical expenses for inpatients (*In-patient*) (25).

To account for inflation, we deflated the expense-related indicators using the consumer price index, with the initial year of the data

serving as the base period. All five indicators were transformed using logarithmic scales.

Additionally, the accessibility of medical resources and the affordability of health services in a region may be influenced by whether the region is an NCMR pilot province, as well as by various regional characteristics or random factors. Therefore, we included a series of control variables from different perspectives: regional environment (26, 27), population (12), economy (11), and industrial structure (28). The selected control variables were: air pollution (*AP*), represented by sulfur dioxide emissions; water pollution (*WP*), represented by chemical oxygen demand emissions; environmental greening (*EG*), expressed as *per capita* park green area; population size (*PS*), expressed as total population; economic development (*ED*), quantified by *per capita* GDP; and industrial structure (*IS*), quantified by the proportion of added value of the secondary industry in GDP.

Non-proportional data were logarithmically transformed and winsorized at the 1st and 99th percentiles before regression analysis. This process helps mitigate the influence of extreme values on the estimates without reducing the sample size.

This study focuses on 31 provinces in mainland China (excluding Hong Kong, Macao, and Taiwan) over the period from 2006 to 2021. Data for all indicators were obtained from the China *Health and Family Planning Statistical Yearbook, the China Health Statistics Yearbook, the China Statistics Yearbook on Environment*, and the National Bureau of Statistics of China website. Missing values were addressed using interpolation. Descriptive statistics for the main variables are presented in Table 1.

3.2 Empirical strategies and model construction

3.2.1 Staggered DID model

Existing studies commonly use the DID model to assess policy effects. This model combines "differences before and after the intervention" with "differences between the experimental and control groups" using panel data, effectively controlling for factors unrelated to the intervention and providing a true assessment of the policy's impact.

In our study, we applied the DID model to evaluate the impact of China's NCMR. Given that the pilot provinces were introduced at two different time points, we used the Staggered DID method as our benchmark model for estimating the average policy effect. This method is well-suited for assessing the effects of a policy implemented incrementally over time, aligning with our study design.

Based on the methodology of Beck et al. (29), the benchmark regression model used in the study is specified as follows:

$$Y_{it} = \alpha + \beta \times NCMR_{it} + \gamma X_{it} + \delta_t + \mu_i + \varepsilon_{it} \quad (1)$$

where i and t represent the province and year, respectively. Y_{it} is the dependent variables, i.e., *Doctor*, *Nurse*, *Sickbed*, *Out-patient*, and *In-patient*, which represent the medical resources and expenditures for province i in year t. $NCMR_{it}$ indicates whether province i is the pilot province of NCMR in year t (1 for inclusion and 0 for non-inclusion). X_{it} represents a series of control variables. δ_t is the time fixed effect.μ_i is the regional fixed effect. ε_{it} is the random error (Equation 1). We mainly focused on the regression coefficient β of $NCMR_{it}$, which indicates the effect of NCMR.

3.2.2 SCM

The SCM, first proposed by Abadie and Gardeazabal (30), aims to create a "counterfactual" comparison unit for policy-affected provinces. It does so by constructing a synthetic control group through weighted combinations of potential control units, effectively simulating the conditions of the pilot provinces had they not been affected by the NCMR. SCM offers several advantages: it reduces selection bias, addresses endogeneity, and mitigates subjectivity in the selection of the control group (31).

The application of SCM is as follows: The dependent variables, including *Doctor*, *Nurse*, *Sickbed*, *Out-patient,* and *In-patient*, in period $t \in [1,T]$ of $K+1$ provinces are obtained. S_{it}^N denotes the dependent variables of province i in year t when NCMR was not implemented, whereas S_{it}^I denotes the variables when NCMR was implemented. If T_0 is the implementation node of NCMR and $t \le T_0$, $S_{it}^N = S_{it}^I$, whereas when $t > T_0$, $\alpha_{it} = S_{it}^I - S_{it}^N$ is the policy effect. For the pilot provinces, S_{it}^I, but not S_{it}^N, can be observed and was estimated using the model proposed by Abadie et al. (32):

$$S_{it}^N = \delta_t + \theta_t Z_i + \lambda_t \mu_i + \varepsilon_{it} \quad (2)$$

where δ_t is the time fixed effect. Z_i indicates the predictive control variables, including *AP*, *WP*, *EG*, *PS*, *ED*, *ID*, and the dependent variables in 2007, 2009, and 2011. λ_t is the common factor vector. μ_i represents the regional fixed effect. ε_{it} is the unobservable instantaneous shock at the province level (Equation 2).

Consider the scenarios where the first province ($i=1$) has implemented NCMR, whereas the remaining K provinces ($i=2,3,\cdots,K+1$) have not implemented it. In this scenario, $W=(w_2,w_3,\cdots,w_{K+1})$ is a weight vector, where $w_k \ge 0$,

TABLE 1 Descriptive statistics.

Variables	Observations	Mean	SD	Min	Max
Doctor	496	1.884	0.707	0.748	5.500
Nurse	496	2.250	0.978	0.560	6.360
Sickbed	496	4.726	1.481	1.600	8.340
Out-patient	496	4.965	0.340	3.615	6.161
In-patient	496	8.582	0.368	7.678	9.833
AP	496	12.476	1.500	7.550	14.341
WP	496	12.722	1.066	9.776	14.405
EG	496	11.922	3.155	5.890	19.960
PS	496	8.112	0.848	5.704	9.404
ED	496	10.549	0.615	9.151	11.963
IS	496	41.964	8.356	17.254	59.388

Doctor, the number of licensed physicians per 1,000 population; *Nurse*, the number of registered nurses per 1,000 population; *Sickbed*, the number of sickbeds in medical institutions per 1,000 population; *Out-patient*, per capita per time medical expense for out-patients; *In-patient*, per capita medical expense for in-patients; *AP*, air pollution; *WP*, water pollution; *EG*, environmental greening; *PS*, population size; *ED*, economic development; *IS*, industrial structure; SD, standard deviation.

$w_2 + w_3 + \cdots + w_{K+1} = 1$. The vector W represents a virtual synthetic control combination.

Abadie et al. (32) proved that when $t > T_0$, $\sum_{k=2}^{K+1} w_k^* S_{kt}^N$ can be considered an unbiased estimate of S_{1t}^N. The policy effect can be estimated as follows:

$$\hat{\alpha}_{1t} = S_{1t}^I - S_{1t}^N = S_{1t}^I - \sum_{k=2}^{K+1} w_k^* S_{kt}^N, t \in [T_0 + 1, \cdots, T] \quad (3)$$

Using the aforementioned formulae, $\hat{\alpha}_{1t}$ (the policy effect) was estimated based on the weight vector W^* (Equation 3).

4 Results

4.1 Results of staggered DID test

4.1.1 Benchmark regression results

The average impact of NCMR on medical resources and expenditures in the pilot provinces was estimated using the Staggered DID model, as shown in Table 2. The first three columns represent the effect of NCMR implementation on regional medical resources, characterized by *Doctor*, *Nurse,* and *Sickbed*. In columns (1) and (2), the regression coefficients of NCMR, the core explanatory variable, are significantly positive at the 5% level, while the coefficient in column (3) is positive but not significant. This suggests that, compared to non-pilot provinces, the number of doctors and nurses increased by 12.6 and 19.8%, respectively, in the pilot provinces.

The last two columns show the NCMR's effect on medical expenditures, characterized by *Out-patient* and *In-patient*. The coefficient in column (4) is negative but not significant, while the coefficient in column (5) is significantly negative, indicating that NCMR played a key role in reducing inpatient medical expenses. *Per capita* inpatient medical costs decreased by 7.2% in the pilot provinces. Overall, the results demonstrate some success in improving the accessibility and affordability of medical resources and services.

4.1.2 Parallel trend test

The validity of the Staggered DID model depends on the parallel trends assumption, which posits that the dependent variables should follow the same trend in both the pilot and non-pilot provinces before policy implementation. To assess this, following the approach of Jacobson et al. (33), we employed the Event Study Method by constructing the following model to investigate parallel trends:

$$Y_{it} = \alpha + \sum_{t=-9}^{t=6} \beta_t \times NCMR_{it} + \gamma X_{it} + \delta_t + \mu_i + \varepsilon_{it} \quad (4)$$

Our focus is on the significance of β_t, with the criterion for passing the test being a non-significant β_t prior to the implementation of NCMR ($t < 0$) (Equation 4). The base year is set as 2006 to avoid multicollinearity. The parallel trend test results for *Doctor*, *Nurse*, and *In-Patient* are presented in Figure 2. The non-significant β_t ($t < 0$) in Figures 2A,C indicates no systematic difference in the number of licensed physicians or inpatient medical expenses between the experimental and control groups before NCMR implementation, confirming the validity of the Staggered DID model.

Additionally, for each dependent variable, we tested the difference in β_t before and after the policy implementation. The coefficient differences for *Doctor* and *In-Patient* are 0.546 ($p < 0.10$) and-0.411 ($p < 0.05$), respectively, further confirming the impact of NCMR. These results indicate a significant increase in licensed physicians and a notable reduction in inpatient medical expenses following the policy. Next, we will conduct a placebo test for the *Doctor* and *In-patient* variables, which passed the parallel trend test.

4.1.3 Placebo test

Admittedly, significant estimates could also result from unobservable random factors. Therefore, the baseline regression results need to be validated by randomly assigning pilot provinces and policy implementation times. Specifically, a new variable $NCMR_{it}^{'}$ is randomly generated to replace the original explanatory variable $NCMR_{it}$ in the regression analysis, producing an incorrect estimation coefficient β'. This process is repeated 500 times to complete the placebo test (Figure 3).

The placebo tests for *Doctor* and *In-patient* are illustrated in Figures 3A,B. The results show that β' values are concentrated around 0 and follow a normal distribution, while the true estimation coefficient β (represented by the dashed line) lies outside the range of all the incorrect coefficients. This suggests that the actual estimation is unlikely to have been influenced by random factors, confirming that the placebo test is successfully passed (Figures 3A,B).

TABLE 2 Benchmark regression results based on staggered DID model.

Variables	(1)	(2)	(3)	(4)	(5)
	Doctor	*Nurse*	*Sickbed*	*Out-patient*	*In-patient*
NCMR	0.126** (0.052)	0.198** (0.095)	0.251 (0.178)	−0.023 (0.028)	−0.072** (0.027)
Control variables	Yes	Yes	Yes	Yes	Yes
Regional FE	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
N	496	496	496	496	496
R^2	0.951	0.950	0.937	0.969	0.977

Statistics in parentheses are robust standard errors, clustered by province; ** $p < 0.05$. DID, difference-in-differences; *Doctor*, the number of licensed physicians per 1,000 population; *Nurse*, the number of registered nurses per 1,000 population; *Sickbed*, the number of sickbeds in medical institutions per 1,000 population; *Out-patient*, per capita per time medical expense for out-patients; *In-patient*, per capita medical expense for in-patients; *NCMR*, a core explanatory variable means whether to implement national comprehensive medical reform; *FE*, fixed effect; *N*, the number of samples.

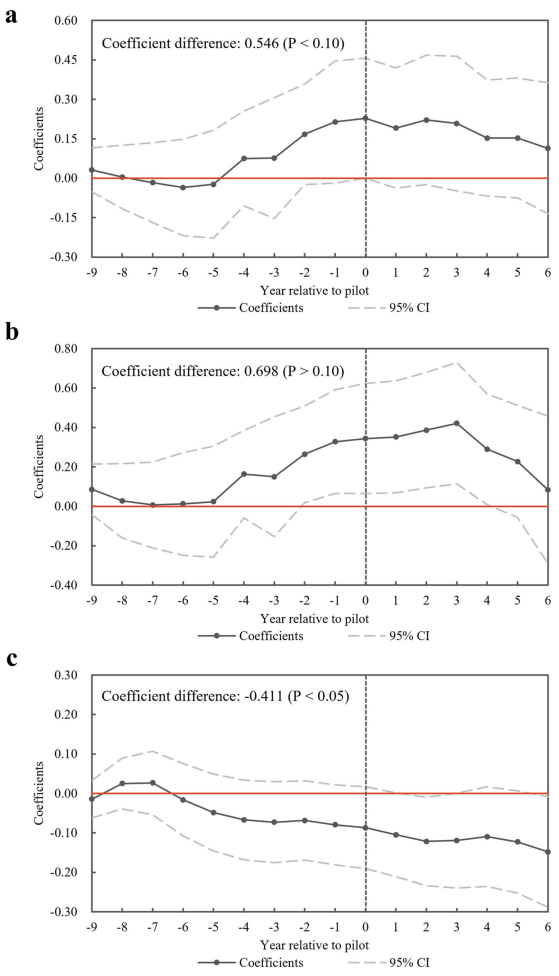


FIGURE 2
Results of the parallel trend test. **(a)** Test results for dependent variable *Doctor*. **(b)** Test results for dependent variable *Nurse*. **(c)** Test results for dependent variable *In-patient*.

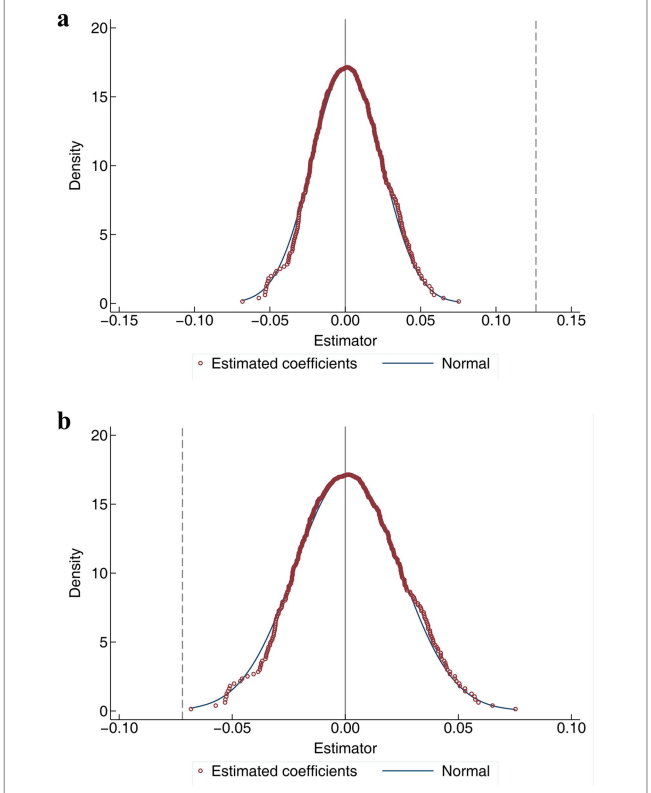


FIGURE 3
Results of the placebo test. **(a)** Test results for dependent variable *Doctor*. **(b)** Test results for dependent variable *In-patient*.

4.2 Results of SCM test

4.2.1 Provincial policy effect evaluation

The heterogeneity of policy shocks across different pilot provinces will be examined in this section. Specifically, the impact of NCMR on increasing licensed doctors and reducing in-patient medical expenses in individual pilot provinces will be analyzed using SCM. Table 3 lists the control variables and their weights used by SCM to construct the "synthetic provinces" for the two dependent variables, *Doctor* and *In-patient*. The comparison between each pilot province and its "synthetic province" in terms of *Doctor* and *In-patient* is depicted in Figure 4, with the vertical dashed line representing the implementation of NCMR (2015 or 2016). The closer the real values are to the fitted values before the implementation (left side of the dashed line), the better the fit of the SCM. In contrast, the gap between the real and fitted values after the implementation (right side of the dashed line) reflects the policy effect.

From the results, although the average effect of NCMR has been validated by multiple tests, only Jiangsu, Zhejiang, and Chongqing have shown both an increase in the number of licensed physicians and a decrease in in-patient medical expenses following the policy. Additionally, in-patient medical expenses have declined in Anhui, Qinghai, Sichuan, and Ningxia, while Shaanxi has experienced an increase in the number of licensed physicians. However, no notable changes in either variable were observed in Fujian, Shanghai, or Hunan.

4.2.2 Placebo test

In accordance with the permutation test proposed by Abadie et al. (32), a placebo test was conducted for the analyses of *Doctor* and *In-patient* in Jiangsu, Zhejiang, and Chongqing. This test assumed that all non-pilot provinces implemented NCMR in 2015 or 2016, allowing for a comparison of the policy effect between the pilot and non-pilot groups. To enhance accuracy, non-pilot provinces with a root mean square prediction error that was 1.5 times higher than that of the pilot provinces before NCMR implementation were excluded from the analysis.

Figure 5 illustrates the experimental effects in Jiangsu, Zhejiang, and Chongqing (solid lines) compared to those in other non-pilot provinces (dashed lines). For the variable *Doctor*, the effects in the three pilot provinces remain around zero before NCMR implementation (to the left of the vertical dashed line), but increase afterward (to the right of the vertical dashed line). Specifically, the solid lines are consistently above the dashed lines prior to 2019. However, after 2019, the effects in the pilot provinces start to diminish and are gradually surpassed by the placebo effects of several non-pilot provinces, indicating a slight decline in the impact of NCMR on the number of physicians.

TABLE 3 Weighting combinations used to synthesize pilot provinces.

DV: *Doctor*	Jiangsu	Anhui	Fujian	Qinghai	Shanghai	Zhejiang	Hunan	Chongqing	Sichuan	Shaanxi	Ningxia
Beijing	0	0	0	0.028	0.144	0.140	0.012	0	0	0	0
Tianjin	0	0	0	0	0	0	0	0	0	0	0
Hebei	0	0	0	0	0	0	0	0	0	0	0
Shanxi	0	0	0	0.133	0	0	0	0	0	0	0
Inner Mongolia	0	0	0	0	0	0	0	0	0	0.210	0
Liaoning	0.148	0	0	0	0	0	0	0	0	0	0
Jilin	0	0	0	0	0.856	0	0	0	0	0	0.533
Heilongjiang	0	0	0	0	0	0	0	0	0	0	0
Jiangxi	0	0.166	0	0	0	0	0	0	0	0.090	0
Shandong	0.358	0	0.199	0.451	0	0.860	0	0.142	0.460	0	0.372
Henan	0	0.322	0.401	0	0	0	0.605	0.653	0.285	0.178	0
Hubei	0.379	0	0	0	0	0	0.231	0	0	0	0
Guangdong	0.116	0	0.399	0.107	0	0	0	0	0	0	0
Guangxi	0	0	0	0	0	0	0	0	0.255	0	0
Hainan	0	0	0	0.281	0	0	0.059	0	0	0	0
Guizhou	0	0.512	0	0	0	0	0.066	0.205	0	0.232	0
Yunnan	0	0	0	0	0	0	0	0	0	0	0
Tibet	0	0	0	0	0	0	0.026	0	0	0.042	0.095
Gansu	0	0	0	0	0	0	0	0	0	0	0
Xinjiang	0	0	0	0	0	0	0	0	0	0.248	0

(Continued)

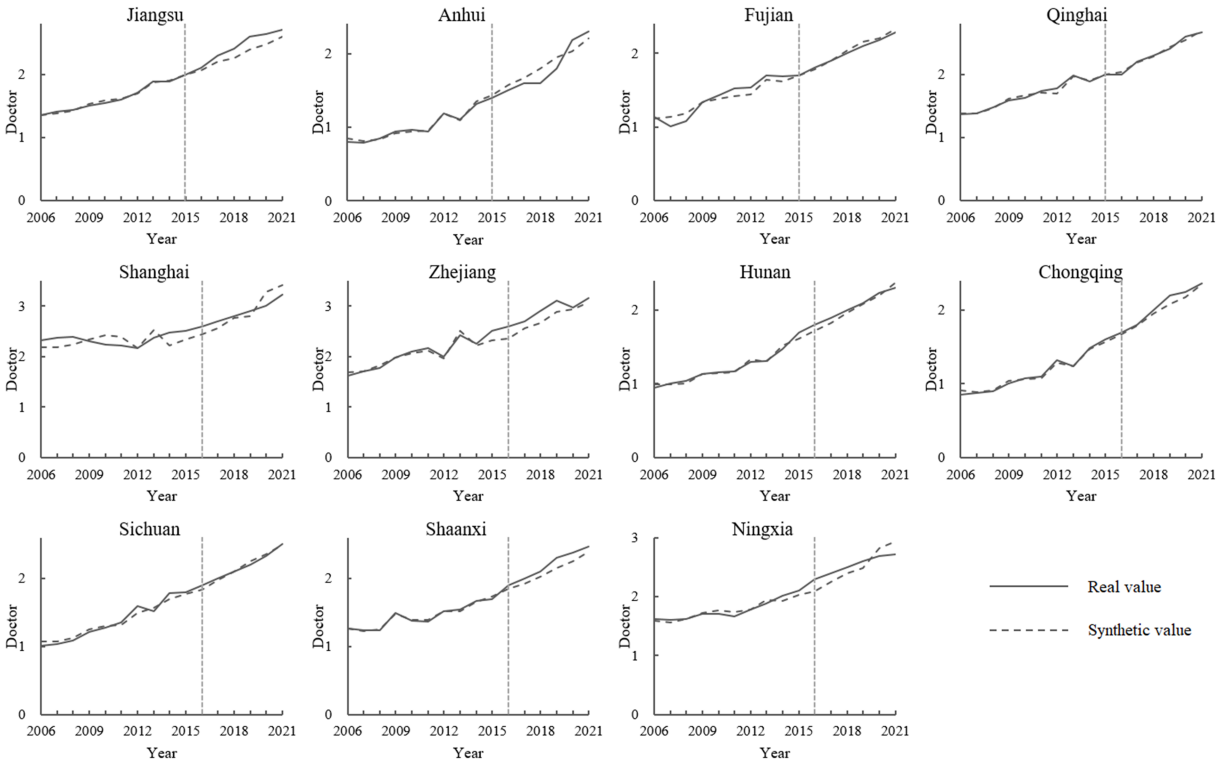
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TABLE 3 (Continued)

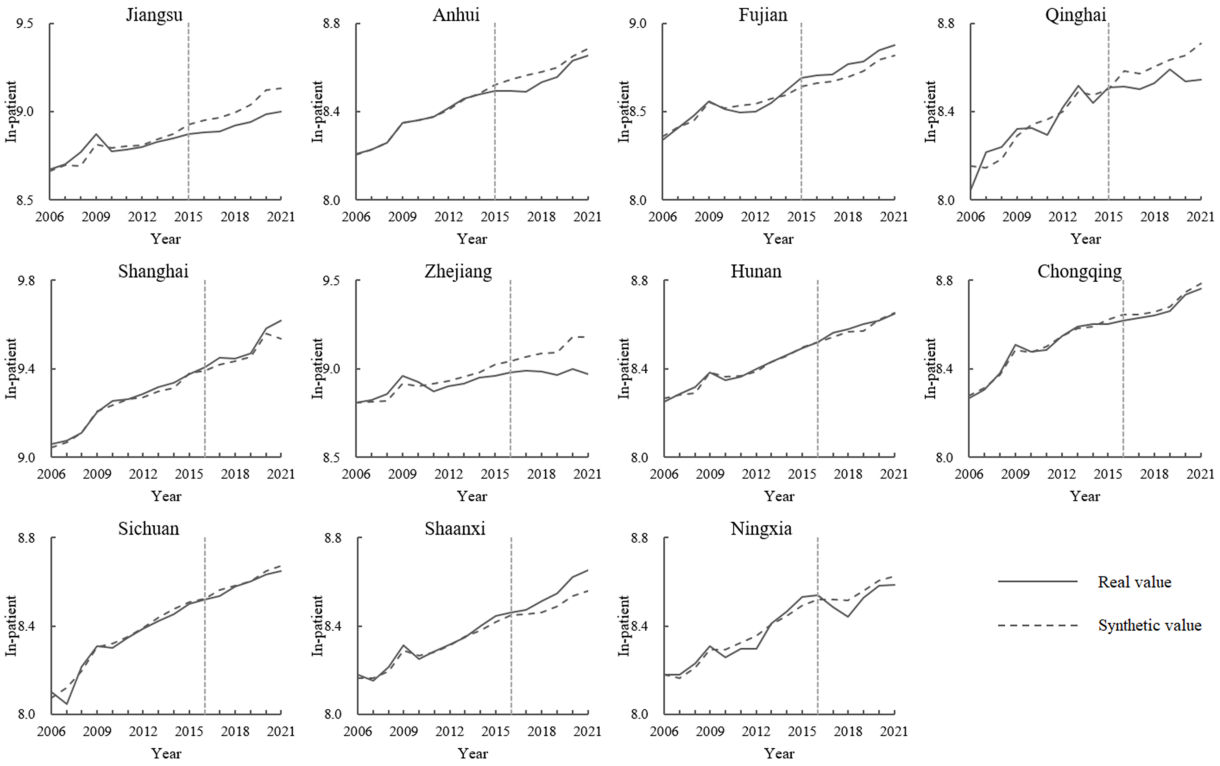
DV: *In-patient*	Jiangsu	Anhui	Fujian	Qinghai	Shanghai	Zhejiang	Hunan	Chongqing	Sichuan	Shaanxi	Ningxia
Beijing	0.119	0	0	0	0.445	0.443	0	0	0.035	0.021	0
Tianjin	0	0.013	0	0	0.416	0	0	0	0	0	0
Hebei	0	0	0	0	0	0	0	0	0	0	0
Shanxi	0	0.020	0	0	0	0	0	0	0	0	0
Inner Mongolia	0	0	0	0	0	0	0	0.078	0.089	0	0
Liaoning	0.374	0	0.536	0	0	0	0	0.301	0.042	0.106	0
Jilin	0	0	0	0	0	0	0	0	0	0	0
Heilongjiang	0	0.075	0	0	0	0	0	0	0	0	0
Jiangxi	0	0	0	0	0	0	0	0	0	0.106	0
Shandong	0	0.121	0	0	0.109	0	0	0	0.057	0.125	0.488
Henan	0	0.139	0	0	0	0	0.090	0	0.495	0	0
Hubei	0	0	0	0	0	0	0	0	0	0	0
Guangdong	0.507	0.186	0.172	0	0.029	0.212	0.320	0	0	0	0
Guangxi	0	0	0	0	0	0	0	0	0	0	0
Hainan	0	0	0	0.549	0	0	0	0.398	0	0	0
Guizhou	0	0	0	0.249	0	0	0	0	0	0.318	0.342
Yunnan	0	0.364	0.293	0	0	0.346	0.590	0.223	0.283	0.323	0.170
Tibet	0	0	0	0.202	0	0	0	0	0	0	0
Gansu	0	0.082	0	0	0	0	0	0	0	0	0
Xinjiang	0	0	0	0	0	0	0	0	0	0	0

DV, dependent variable; *Doctor*, the number of licensed physicians per 1,000 population; *In-patient*, per capita medical expense for in-patients.

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Dependent variable: *Doctor*



Dependent variable: *In-patient*

FIGURE 4
Comparison of real and synthetic values of dependent variables in pilot provinces.

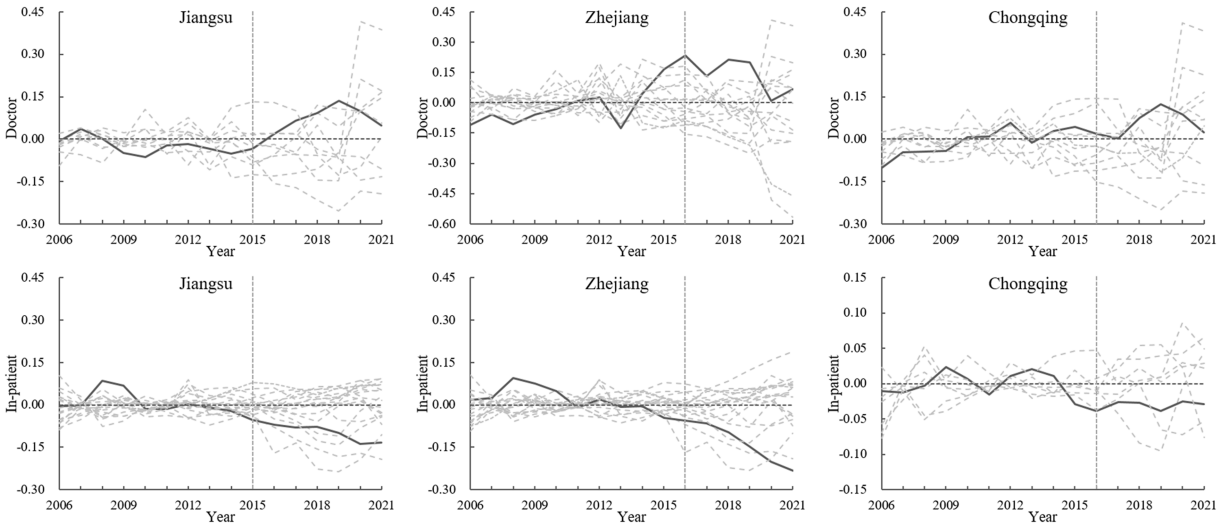


FIGURE 5
Results of the permutation test.

In contrast, for the variable *In-patient*, the experimental effects in the three pilot provinces remain substantial after the policy implementation. The solid lines are generally below the majority of the dashed lines, highlighting that NCMR significantly contributes to reducing in-patient medical expenses.

4.3 Analysis of policy characteristics

From the perspective of the NCMR policy effect in each pilot province, only Jiangsu, Zhejiang, and Chongqing have successfully achieved both an increase in medical resources and a reduction in residents' medical burden. This outcome can be attributed to the nature of NCMR as a top-down policy, where each pilot province is required to adapt and tailor the policy details to its specific conditions. Consequently, different pilot provinces may be at various stages of reform and exhibit diverse outcomes. To understand this variation, it is essential to examine the policy characteristics and implementation strategies of Jiangsu, Zhejiang, and Chongqing.

To address this question, we analyzed related policy descriptions and news reports from the official websites of the provincial governments of Jiangsu, Zhejiang, and Chongqing, as well as from mainstream media. We used Python to perform word frequency statistics to examine the specific policy measures associated with NCMR in these provinces. This analysis aims to explore the reasons behind the successful reform outcomes and provide guidance for other provinces implementing healthcare reforms. The word frequency statistics are presented in Table 4. To clarify the differences and focal points in the NCMR policies of these three provinces, we refined the initial statistical results by removing common nouns such as "service," "medical," and "health" that appeared in all relevant texts. These terms were excluded as they did not provide insights into specific measures or methods outlined in the policy documents.

First, high-frequency words in the policy and news texts from Jiangsu include "remuneration," "talents," "salary," and "medical staff." As a pioneering economic region and one of the initial NCMR pilot areas, Jiangsu started with a strong foundation and considerable momentum for reform. The focus here has been on improving the remuneration of medical personnel and addressing medical expenses, with a variety of supporting policies introduced. Specifically, to increase the number of medical staff and enhance their motivation, Jiangsu has implemented salary reforms, such as encouraging an annual salary system for hospital leaders and offering annual or negotiated salaries for high-level talents. Additionally, efforts to reduce medical expenses have included price reforms to lower the proportion of drug expenditures for both out-patient and in-patient treatments (34). Control indicators have also been established to monitor and manage the growth of medical expenses.

Second, high-frequency words in Zhejiang's policy and news texts include "Internet," "data," "medical community," and "sinking." Zhejiang's approach to NCMR emphasizes "digital health" and the development of "Internet and medical health" services. The province has focused on AI-assisted clinical decision support, electronic medical insurance billing via blockchain, and mobile payment systems to enhance healthcare delivery and data sharing. Unified platforms for electronic prescriptions and Internet hospital services are being developed to ensure data traceability, whole-process supervision, and more efficient diagnosis and treatment. Additionally, Zhejiang has completed the construction, evaluation, and monitoring of county-level medical communities to promote the creation of digital medical communities and facilitate the "double-sinking" of medical resources (both hospitals and doctors), as well as improve management, financing, and investment (35). This approach has led to significant improvements in the medical capacity and environment of primary hospitals, enhancing the accessibility of health resources (36).

Third, Chongqing, located in relatively underdeveloped western China, provides a replicable model for the second batch of pilot provinces. High-frequency words in the policy and news texts include "medicine," "supervision," "traceable," and "pharmaceutical exchange" (Table 4). To reduce residents' medical burden, Chongqing has established a traceability system for medical information, ensuring full-process traceability of pharmaceuticals and equipment from

TABLE 4 Policy word frequency statistics for Jiangsu, Zhejiang, and Chongqing.

Jiangsu		Zhejiang		Chongqing	
Word	Frequency	Word	Frequency	Word	Frequency
Remuneration	56	Internet	59	Medicine	65
Contract	40	Wisdom	34	Grass-roots level	63
Personnel	34	Information	29	Supervision	51
Expenses	33	Data	26	Purchase	47
Talents	29	Intelligence	25	Information	41
Family doctor	28	Medical community	23	Traceable	32
Salary	25	Digital	22	Flow	21
Medical staff	18	Sinking	20	Pharmaceuticals and equipment	21
Price	17	Sharing	19	Pharmaceutical exchange	16
Subsidy	15	Artificial intelligence	11	Rural towns	10

"manufacturers-operators-institutions-patients." This system enhances drug supply reliability and has led to a 53% reduction in the prices of 157 drugs. For improving resource accessibility, Chongqing integrates urban and rural medical resources by supporting collaborations between municipal hospitals and district health centers, and promoting the development of multi-district hospitals. Additionally, Chongqing guides medical personnel to grassroots levels and fosters the co-construction and sharing of medical resources, which is likely to enhance individual satisfaction with medical care.

4.4 Extensibility analysis

4.4.1 Factors influencing policy effectiveness

The results of the basic regression analysis indicated that NCMR generally increased medical resources, as measured by the number of licensed physicians (*Doctor*), and alleviated the medical burden of residents, as reflected by in-patient medical expenditure (*In-patient*) in the pilot provinces. However, the policy effects varied across different provinces. What factors might influence the effectiveness of NCMR? To address this question, this study will explore several potential influencing factors.

(1) The degree of population aging, measured by the proportion of individuals aged over 65 in the total population. Older adult individuals typically have a *per capita* out-patient volume and hospitalization rate 3–4 times higher than those of children, youth, and adults (37), leading to greater demand for medical resources. Additionally, a higher proportion of older adult people is a significant factor contributing to increased healthcare expenditure (38). Therefore, the degree of population aging is expected to influence the policy effectiveness of NCMR. Provinces with a lower degree of population aging may achieve better reform results.

(2) Population health status, which is often measured by mortality rates (39, 40). In this study, mortality is used as an indicator of regional population health status, with lower mortality reflecting higher overall health levels. Generally, poorer population health conditions lead to greater demand for medical resources and a heavier medical burden. Therefore, NCMR is expected to achieve better outcomes in provinces with better population health status.

4.4.2 Extensibility analysis results

Before analysis, the samples were grouped based on the upper and lower tertiles of the proportion of the older adult population and regional mortality rates, respectively. Samples above the upper tertile were categorized as the "high degree of population aging (high-AG)/low population health status (low-HE)" group, while those below the lower tertile were classified as the "low degree of population aging (low-AG)/high population health status (high-HE)" group. The resulting sub-samples were then analyzed using the Staggered DID model, and the results are presented in Table 5.

From columns (1) and (2), as well as (3) and (4), it is evident that the low-AG group has experienced more pronounced policy effects following the implementation of NCMR compared to the high-AG group. Specifically, the low-AG group shows higher estimates for increasing the number of licensed physicians (0.199** vs. 0.100**) and more significant reductions in in-patient medical expenses (−0.100* vs. −0.007).

Similarly, columns (5) and (6) reveal that the high-HE group experienced a greater policy effect in increasing the number of licensed physicians. However, in columns (7) and (8), despite non-significant coefficients due to the reduced sample size, the high-HE group achieved a lower reduction in in-patient medical expenses compared to the low-HE group, with a significant difference (−0.066, $p < 0.05$) between the two groups. This indicates that the high-HE group performed better in reducing in-patient medical expenses to a certain extent.

On one hand, considering the relationship between population aging and medical resources, the increasing older adult population has significantly expanded the demand for medical resources. However, the current adjustments to medical resources in China have not fully kept pace with the growth in the older adult population, leading to an overall insufficiency in medical resources (41). Additionally, the rise in the older adult population accelerates the depletion of available medical resources (42). Consequently, population aging negatively impacts the availability of medical resources and poses a challenge to the effectiveness of the NCMR policy.

TABLE 5 Extensibility analysis results.

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Basis for grouping	High-AG	Low-AG	High-AG	Low-AG	High-HE	Low-HE	High-HE	Low-HE
Variables	*Doctor*		*In-patient*		*Doctor*		*In-patient*	
NCMR	0.100** (0.046)	0.199** (0.078)	−0.007 (0.017)	−0.100* (0.048)	0.405*** (0.068)	0.013 (0.033)	−0.073 (0.042)	−0.008 (0.020)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	147	146	147	146	150	147	150	147
R^2	0.980	0.933	0.994	0.972	0.950	0.988	0.991	0.981

Statistics in parentheses are robust standard errors, clustered by province; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

On the other hand, population aging increases the depreciation rate of health capital, with older individuals requiring more investment in healthcare services (43). This, in turn, amplifies the impact on public health expenditure (44). Many studies have identified aging as a significant driver of rising healthcare spending, projecting that by 2025, approximately 20% of the increase in healthcare costs will be attributed to an aging population (45, 46). Although provinces with higher levels of aging have substantial potential for reform, the dual challenge of increased demand for medical resources and elevated healthcare expenditure due to aging can create greater resistance to reform. This resistance can lead to less effective outcomes for the NCMR in regions with higher population aging.

Additionally, the impact of regional overall population health status on the effectiveness of NCMR reveals that the policy is less effective in areas with poorer health outcomes. Consistent with our findings, Sun et al. (47) observed that medical resources and health conditions in rural areas of China lagged significantly behind those in urban areas. This disparity poses a substantial challenge for healthcare reform, resulting in notably weaker effects of NCMR in rural regions compared to urban areas with better health levels. Poorer health conditions typically lead to higher demand for medical services and increased medical expenses, creating additional obstacles for NCMR in improving medical resources and reducing costs.

5 Discussion

Enhancing the accessibility of medical resources and establishing an affordable medical care system for residents have long been primary goals of global healthcare reform. This study effectively estimates and verifies the average impact of China's NCMR on increasing the number of licensed physicians and reducing in-patient medical expenses using the staggered DID model and a series of tests. Additionally, SCM results highlight that NCMR achieves these effects only in certain pilot provinces, with noticeable provincial heterogeneity influenced by factors such as population aging and health status. These findings offer valuable macro-level empirical evidence and can guide adjustments to the reform strategy in the next stage.

Our study shows that, in the pilot provinces, NCMR effectively increases the number of licensed physicians but has no significant impact on the number of registered nurses and sickbeds in healthcare institutions. This may be because NCMR primarily focused on enhancing the training and number of general practitioners. By implementing license registration reforms, expanding the scope of practice, ensuring adequate remuneration, and prioritizing general practitioners, the policy has led to a noticeable increase in the number of practicing physicians. However, this also underscores the need for future expansion in other medical resources, such as nurses and sickbeds.

Regarding the affordability of medical services, NCMR effectively reduces *per capita* medical expenses for in-patients but has no impact on *per capita* out-patient medical expenses. This aligns with findings from Wang et al. (48) and Nie et al. (49). The likely reason is that NCMR, as a comprehensive policy, aims to balance reducing the medical burden on residents while maintaining the financial sustainability of medical staff and hospital operations. Specifically, by canceling drug markups and reducing inflated drug prices, NCMR shifts some financial burden from pharmaceuticals to medical services. This shift is intended to reflect the labor value of medical personnel and adjust hospital income structures, reducing reliance on pharmacy profits to subsidize medical services. Consequently, while drug expenses decrease, the overall out-patient expenditure—which includes drug costs, medical examinations, and service fees—remains unchanged (48).

Regarding provincial heterogeneity, Jiangsu, Zhejiang, and Chongqing have successfully achieved both an increase in medical resources, as indicated by the number of physicians, and a reduction in residents' medical burden, as measured by in-patient expenses. In contrast, Anhui, Qinghai, Sichuan, and Ningxia have only managed to reduce in-patient expenses, while Shaanxi has only succeeded in increasing the number of qualified doctors. The remaining provinces have not shown the expected improvements. This highlights that, within a top-down reform framework, each pilot province must tailor its implementation and detailed reform regulations to its local conditions and existing medical system infrastructure. As a result, the stages and outcomes of the reform vary across different provinces.

However, there are some limitations to this study. First, our evaluation of the NCMR policy effects is conducted from a macro-level perspective (provincial level), and lacks analysis at the meso-level (e.g., public hospitals) and micro-level (e.g., individual residents). Second, the study relies on traditional causal inference models for evaluation. Future research could benefit from incorporating big data and AI technologies, utilizing machine learning models to more accurately identify and quantify policy effects.

6 Conclusion

Based on provincial panel data from mainland China spanning 2006–2021, this study employs the Staggered DID model, SCM, and grouping regression to evaluate the average policy effect of NCMR and explore provincial heterogeneity and influencing factors. The findings are as follows: First, with regard to the accessibility of medical resources, NCMR effectively increased the number of licensed physicians by 12.6% in the pilot provinces. Second, with regard to the affordability of medical services, NCMR reduced the *per capita* medical expense for in-patients by 7.2%. Third, the policy effects varied across provinces. Jiangsu, Zhejiang, and Chongqing achieved both an increase in the number of licensed physicians and a decrease in in-patient medical expenses, whereas other provinces either saw only one of these effects or no significant changes. Finally, the effectiveness of NCMR is influenced by population aging and health status. Provinces with a low-AG and high-HE experienced more pronounced reform effects.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

XF: Conceptualization, Data curation, Project administration, Writing – original draft, Writing – review & editing. XR: Conceptualization, Funding acquisition, Supervision, Validation, Writing – review & editing. QC: Data curation, Formal analysis, Software, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Determinants of the low use of Thailand's Universal Coverage Scheme: a national cross-sectional study

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Introduction: Thailand's Universal Coverage Scheme (UCS) has increased overall healthcare use by offering free healthcare for about 76% of the entire population since it was introduced in 2002. However, a considerable number of beneficiaries have continued to depend on private healthcare, and the low use of the UCS has been cited as a challenge to accomplishing the policy's goal of universal access to healthcare. Thus, this study divided healthcare use into three patterns (self-medication, private providers, and UCS) and investigated the socio-demographic characteristics of non-users of the UCS and their reasons for non-use.

Methods: A cross-sectional quantitative analysis was performed using data from the 2019 Health and Welfare Survey. UCS beneficiaries aged 15 years or older who had used healthcare during the past month were included in the sample. Descriptive analysis and multinomial logistic regression were performed to analyze associations between patterns of healthcare use and socio-demographic factors chosen based on Aday and Andersen's access to medical care model.

Results: Of the study sample (n = 5,636), about 46.1% used healthcare services outside the UCS delivery system, of whom 33.8 and 12.3% used self-medication and private healthcare providers, respectively. Non-users generally had a higher socio-demographic status than UCS users. Specifically, they were young, had a high income, were employed, lived in urban areas, or did not have a chronic disease. The most common reason for non-use of the UCS was accessibility barriers (59.6%; e.g., long queues in public providers), followed by availability (25.4%; e.g., limited operating hours of public providers) and quality barriers (14%; e.g., unsureness of the quality of medicine offered by public providers). Moreover, self-medication users tended to be concerned about availability barriers, while private-provider users tended to be concerned about quality barriers for using the UCS.

Conclusion: Under the UCS policy, there is a gap between the demands for healthcare and the resources assigned to increase the capability of public healthcare providers. That is, the UCS has increased financial accessibility for the use of the UCS (i.e., free healthcare from public providers). However, it probably has not yet increased healthcare resources and infrastructure facilitating the use of the UCS. This may have prevented the UCS from meeting the demands of its intended beneficiaries, especially those in high socio-economic groups, and ultimately forced them to use private healthcare.

KEYWORDS

Universal Coverage Scheme, 30-baht health insurance, public health insurance, healthcare use, healthcare access, Thailand

1 Introduction

Thailand offers universal healthcare coverage by implementing three public health insurance policies: the Civil Servant Medical Benefits Scheme (CSMBS), the Social Security Scheme (SSS), and the Universal Coverage Scheme (UCS). The CSMBS, SSS, and UCS are insurance policies for people in the public, private, and informal employment sectors, and they cover about 10, 14, and 76% of the population, respectively (1, 2). The implementation costs of all three schemes, including managerial costs of the system of public healthcare providers, accounted for about 70.4% of the nation's total health expenditure in 2021 (3).

The UCS, which is the largest insurance policy, was introduced in 2002 and has since offered free healthcare to about 76% of the population in the informal employment sector (2). The UCS is a tax-financed non-contributory policy. The policy, also known as "30-baht health insurance," offers comprehensive healthcare benefits for 30 Thai baht, which is equal to about 0.90 US dollars. The benefits include acute and rehabilitative healthcare and preventive healthcare efforts, such as routine health checks and essential immunizations. The policy requires beneficiaries to receive healthcare at designated healthcare providers, namely public primary healthcare providers. Beneficiaries who bypass their designated providers have to pay for healthcare out of pocket (4, 5).

The effects of the UCS on healthcare use in Thailand have been extensively studied (2, 6–11). The overall pattern indicates that the UCS has increased overall healthcare use, especially among low socio-demographic groups. Specifically, trend analyses have revealed that the use of public healthcare providers (e.g., hospitalizations and outpatient visits) increased persistently after the UCS was implemented (2, 6, 7). Moreover, studies investigating patterns of healthcare use have revealed that the UCS has increased the use of public healthcare providers while decreasing the use of private modes of healthcare, such as self-medication (e.g., over-the-counter or Thai traditional medicines) and private healthcare providers (e.g., private clinics or hospitals). This pattern was more evident in low socio-demographic groups than in high socio-demographic groups (8–11).

Interestingly, although the UCS has increased overall healthcare use by offering free healthcare, a significant number of beneficiaries have continued to use private healthcare instead of the UCS (11–13). Specifically, a study using national survey data from 2004 showed that about 50% of UCS beneficiaries using healthcare sought care through private means, with about 32 and 18% using self-medication and private healthcare providers, respectively. These non-users generally had a higher socio-demographic status than users of the UCS. Specifically, they had a high income, were highly educated and employed, or lived in urban areas (11). The 50% non-use rate and associated socio-demographic patterns were also reported in two recent studies using the same data from 2007 (12) and 2013 (13), though the use rates of self-medication and private healthcare providers varied slightly across these studies.

Moreover, the low use of public health insurance has been reported in studies from other Southeast Asian countries, particularly Indonesia, Philippines, and Vietnam (12, 14–19). Consistent with previous results from Thailand, these studies indicate that the use of public health insurance increased while the use of private healthcare decreased after the policy implementation. However, the overall use of public health insurance was relatively low due to the high use of private healthcare and the high occurrence of bypassing in high socio-demographic groups. Specifically, a study conducted in Indonesia showed that among all beneficiaries of the National Health Insurance who had used healthcare over the past month, only 42% used the insurance. The other 58% used private healthcare, of whom about 53 and 5% used self-medication and private healthcare providers, respectively. These non-users had a high income, were highly educated and employed, or lived in urban areas (19).

Two contrasting opinions may exist regarding the low use of public health insurance (or the high use of private healthcare). On the one hand, the high use of private healthcare can be considered reasonable since individuals can freely choose the type of healthcare they receive according to their preferences and socio-demographic circumstances. As previous studies have revealed, individuals with a high socio-demographic status prefer private healthcare to public health insurance. If private healthcare is used by high socio-demographic groups because of relatively affordable costs and convenient accessibility, their high use of private healthcare is reasonable.

On the other hand, the high use of private healthcare could be partly due to issues with healthcare offered by public health insurance, such as low accessibility (e.g., long queues) and low availability (e.g., limited healthcare benefits). Such issues may give individuals no choice but to use private healthcare, even if they would rather use public health insurance. This perspective suggests that the high use of private healthcare indicates a gap between people's needs and the provision of healthcare under a public health insurance policy, which should be reduced if the policy's goal is to provide universal access to healthcare.

The stated objective of the UCS is "to equally entitle all Thai citizens to quality health care according to their needs, regardless of their socioeconomic status" [(2), p. 37]. That is, the UCS is an insurance policy founded on the principle of universal access to healthcare for all population groups, rather than particular groups such as low-income groups. Thus, the low use of the UCS is a challenge to accomplishing the policy objective of universal access to healthcare, which has also been cited in previous studies (12, 13).

Previous studies provided a comprehensive understanding of the non-use of the UCS and its associated socio-demographic factors. However, to our knowledge, specific reasons for the non-use of the UCS have been relatively understudied. In addition, since previous studies used relatively outdated data, a study using recent data is required to verify the reliability and validity of previous results. Therefore, the present study investigated patterns of healthcare use to identify determinants of the low use of the UCS. Specifically, by dividing healthcare use into three patterns (self-medication, private providers, and UCS), this study explored the socio-demographic characteristics of non-users of the UCS and their reasons for non-use.

2 Methods

2.1 Data and sample

The present cross-sectional quantitative analysis utilized data from the 2019 Health and Welfare Survey (HWS). The HWS is a national survey providing comprehensive socio-demographic and healthcare-related parameters about the population of Thailand. The survey consists of four main components: (a) socio-demographic characteristics, (b) diseases and healthcare use, (c) lifestyle risk factors, and (d) household characteristics. The National Statistical Office of Thailand conducts and administers the HWS biannually.

The purpose of the HWS is to generate reliable representative statistics at the national level. For this purpose, a stratified two-stage sampling approach is used. Specifically, the survey's scope encompasses households in all municipalities (i.e., urban areas) and non-municipalities (i.e., rural areas) in all 77 provinces of Thailand. The first stratum includes all 77 provinces and the second stratum includes two substrata (i.e., all municipalities and non-municipalities) in each province.

In stage 1, enumeration areas from all municipalities and non-municipalities are chosen according to proportional probability to the population's size. In stage 2, 12–16 households from the chosen enumeration areas in municipalities and 8–12 households from those in non-municipalities are randomly chosen. Accordingly, the HWS can represent a national cross-section of all 77 provinces of Thailand, with equal-sized samples from each province (20).

The 2019 HWS was used because it is the latest report that provides all variables of interest in this study. The National Statistical Office of Thailand carried out the HWS in 2021 and 2023, but the datasets are not suitable for this study. The 2021 HWS was conducted during the COVID-19 pandemic and was not publicly released, and the 2023 HWS does not offer several key pieces of socio-demographic information, including income.

UCS beneficiaries aged 15 years or older who had used healthcare in the past month comprised the sample for analysis. Specifically, the 2019 HWS originally included a total of 63,594 respondents (23,549 households). Among the 63,594 respondents, 52,921 (about 83%) were aged 15 or above. Among them, 40,263 (about 76%) were UCS beneficiaries. Among the beneficiaries, 5,636 (about 14%) had used healthcare in the past month and they were ultimately used as the study sample for analysis.

2.2 Variables and measurement

The pattern of healthcare use (the outcome variable) was measured as a nominal variable with three categories: self-medication, private providers, and UCS. Among the study sample, those using over-the-counter or Thai traditional medicines were included in the category of self-medication, those using private clinics or hospitals were included in the private providers category, and those using the UCS were included in the category of UCS.

Independent variables were chosen based on Aday and Andersen's behavior model of access to medical care (21, 22). This model divides factors associated with healthcare use into three components: predisposing, enabling, and need-for-care factors. Predisposing factors are individual demographic and socio-cultural characteristics determined before the incidence of an illness. Enabling factors refer to individual and community resources facilitating healthcare access. Need-for-care factors refer to subjective (or illnesses) and objective health problems (or diseases) generating the demand for healthcare. The present study used two demographic characteristics (age and sex), five socio-economic status indicators (income, education, employment, marital status, and place of residence), and the presence of chronic disease as predisposing, enabling, and need-for-care factors in the analysis, respectively.

Regarding measurement, age was a nominal variable with four categories (15–30, 31–45, 46–60, and 61 years or older). Income was measured as an income quartile (Q1–Q4) based on household equivalence scale income (23). Marital status (single, married, and divorced) and education (low, middle, and high) were used as a nominal variable and an ordinal variable with three categories, respectively. Regarding marital status, the "divorced" category included individuals who were divorced, widowed, or separated. Regarding education, the "low" category referred to primary school or lower, the "middle" category referred to secondary school, and the "high" category referred to college or higher. The rest of the variables—namely, sex (male and female), employment (yes and no), place of residence (urban and rural), and chronic disease (yes and no)—were dichotomous variables.

In addition, reasons for the non-use of the UCS were classified into four components (availability, accessibility, acceptability, and quality) based on the World Health Organization's Availability, Accessibility, Acceptability, and Quality (AAAQ) framework (24, 25). Barriers related to availability refer to the adequacy of the amount and type of healthcare (e.g., limited healthcare benefits). Barriers related to accessibility indicate the physical (e.g., long distances or long queues) and financial (e.g., costs of healthcare) accessibility of healthcare. Acceptability barriers are related to inequality and unfairness in the provision of healthcare (e.g., patient discrimination or unfriendly staff). Finally, quality barriers refer to acceptable healthcare standards (e.g., perceived quality of healthcare). This study explored reasons for not using the UCS according to these four components and the classified patterns of healthcare use.

2.3 Statistical analysis

Descriptive statistical analysis was first performed to offer summary statistics of the study sample and variables. The bivariate association between the outcome variable (i.e., patterns of healthcare use) and each of the independent variables was then investigated by performing a chi-square test. Then, because the outcome variable was a nominal variable with three categories (self-medication, private providers, and UCS), a multinomial logistic regression (MLR) model was established to investigate the outcome's multivariate associations with the independent variables (26, 27).

The performance of the MLR model was evaluated by the Pearson's goodness-of-fit test. In addition, this study inspected multicollinearity across the independent variables by using the variance inflation factor and the cross-comparison between the crude odds ratio (COR) and adjusted odds ratio (AOR). The variance inflation factor scores ranged from 1.037 to 3.194. Moreover, considerable directional changes between the COR and AOR were not detected in the cross-comparison, indicating the absence of multicollinearity in the MLR model (27). The entire results of the MLR model are presented in Appendix.

Statistical significance was assessed at a p-value of 0.05. For the MLR model, this study used the OR and 95% confidence interval (CI) to assess the directional relationship and statistical significance. IBM SPSS Statistics version 20 was used for all statistical analyses.

3 Results

3.1 Descriptive statistical analysis

Table 1 reveals the results of the descriptive statistical analysis. Among 5,636 UCS beneficiaries aged 15 years or older who had used healthcare over the past month, 53.9% ($n = 3,038$) used the UCS. The other 46.1% ($n = 2,598$) used private healthcare, with 33.8% ($n = 1,904$) and 12.3% ($n = 694$) using self-medication and private healthcare providers, respectively. Non-users (both self-medication and private-provider users) generally had a higher socio-demographic status than UCS users.

Regarding the predisposing factor, the use rate of private healthcare increased with age, indicating that young people tend to use private healthcare while old people tend to use the UCS. Specifically, the use rates of self-medication were 49.5, 45.9, 37.6, and 24.7% in the age groups of 15–30, 31–45, 46–60, and 61 years or older, respectively. For the private providers group, the use rates were

TABLE 1 Results of descriptive statistical analysis.

Variables			Pattern of healthcare use						X^2 test p-value
	Overall (n = 5,636; 100%)		UCS (n = 3,038; 53.9%)		Self-medication (n = 1,904; 33.8%)		Private provider (n = 694; 12.3%)		
	n	%	n	%	n	%	n	%	
Predisposing factors									
Age									<0.001
15–30	461	8.2	153	33.2	228	49.5	80	17.4	
31–45	800	14.2	295	36.9	367	45.9	138	17.3	
46–60	1,772	31.4	887	50.1	666	37.6	219	12.4	
61 or older	2,603	46.2	1,703	65.4	643	24.7	257	9.9	
Sex									0.074
Male	2,222	39.4	1,160	52.2	789	35.5	273	12.3	
Female	3,414	60.6	1,878	55.0	1,115	32.7	421	12.3	
Enabling factors									
Income									<0.001
Q1	2,092	37.1	1,329	63.5	547	26.2	216	10.3	
Q2	1,512	26.8	789	52.2	556	36.8	167	11.0	
Q3	1,246	22.1	605	48.6	477	38.3	164	13.2	
Q4	786	14.0	315	40.1	324	41.2	147	18.7	
Education									<0.001
Low	4,306	76.4	2,506	58.2	1,338	31.1	462	10.7	
Middle	1,154	20.5	466	40.4	498	43.2	190	16.5	
High	176	3.1	66	37.5	68	38.6	42	23.9	
Marital Status									<0.001
Single	648	11.5	286	44.1	278	42.9	84	13.0	
Married	3,506	62.2	1,818	51.9	1,209	34.5	479	13.7	
Divorced	1,482	26.3	934	63.0	417	28.1	131	8.8	
Employment									<0.001
Yes	3,159	56.1	1,436	45.5	1,276	40.4	447	14.2	
No	2,477	44.0	1,602	64.7	628	25.4	247	10.0	
Place of residence									0.024
Urban	2,852	50.6	1,487	52.1	1,006	35.3	359	12.6	
Rural	2,784	49.4	1,551	55.7	898	32.3	335	12.0	
Need-for-care factor									
Chronic disease									<0.001
Yes	2,946	52.3	2,183	74.1	469	15.9	294	10.0	
No	2,690	47.7	855	31.8	1,435	53.4	400	14.9	

about 17.4, 1.73, 12.4, and 9.9% for the same respective age categories. Meanwhile, the use rates of the UCS were about 33.2, 36.9, 50.1, and 65.4% in the same respective categories. However, patterns of healthcare use were not different between the sexes.

In terms of the enabling factors, high socio-economic groups tended to use private healthcare while low socio-economic groups tended to use the UCS. Specifically, the use rates of self-medication (e.g., Q4: 41.2% vs. Q1: 26.2%) and private providers (e.g., Q4: 18.7% vs. Q1: 10.3%) in people with high incomes were higher than in those with low incomes. Highly educated people had higher use rates of self-medication (e.g., Q1: 31.1% vs. Q4: 38.6%) and private providers (e.g., Q1: 10.7% vs. Q4: 23.9%) than people with a low education level. Employed people had higher use rates of self-medication (yes: 40.4% vs. no: 25.4%) and private providers (yes: 14.2% vs. no: 10.0%) than unemployed people. People who were married and single, compared to those who were divorced, had higher use rates of self-medication (e.g., married: 34.5% vs. divorced: 28.1%) and private providers (e.g., married: 13.7% vs. divorced: 8.8%). Regarding place of residence, the use rates of self-medication (urban: 35.3% vs. rural: 32.3%) and private providers (urban: 12.6% vs. rural: 12.0%) were higher in urban people than in rural people.

Regarding the need-for-care factor, patients without a chronic disease tended to use private healthcare, while patients with a chronic disease tended to use the UCS. The use rates of self-medication (yes: 15.9% vs. no: 53.4%) and private providers (yes: 10.0% vs. no: 14.9%) were higher in people without a chronic disease than in those with a chronic disease.

In summary, about 46.1% of all UCS beneficiaries using healthcare services used them outside the UCS delivery system, of whom 33.8 and 12.3% used self-medication and private healthcare providers, respectively. Compared to UCS users, non-users generally had a higher socio-demographic status. They were younger, had a higher income, were highly educated, employed, married, living in urban areas, and did not have a chronic disease.

3.2 Multinomial logistic regression analysis

Table 2 presents the results of the MLR model. The *p*-value of the Pearson chi-square goodness-of-fit test was 0.739, indicating that the MLR model did not reveal a lack of fit to the data. Consistent with the descriptive statistical analysis, the MLR model reveals that non-users of the UCS were more likely than users to have a high socio-demographic status.

Specifically, the MLR model of self-medication (vs. UCS) indicates that self-medication users tended to be young, have a high income, be employed, live in urban areas, and not have chronic diseases compared to UCS users. People aged 15–30 and 31–45 years were 1.53 and 1.36 times more likely to use self-medication than those aged 61 years or older. However, the use of self-medication was not different between people aged 46–60 and those aged 61 years or older.

In terms of income, people in Q2, Q3, and Q4 were 1.59, 1.56, and 2.11 times more likely to use self-medication than those in Q1. Employed people and those living in urban areas had a 1.38 and 1.17 times higher use of self-medication than unemployed and rural people, respectively. Lastly, people without a chronic disease were 6.84 times more likely to use self-medication than those with a chronic disease.

In addition, the MLR model of private providers (vs. UCS) reveals that private-provider users were more likely to be young, have a high income, be highly educated, married, and employed, and not have a chronic disease than UCS users. People aged 15–30 and 31–45 years had a 1.82 and 1.44 times higher use of private providers than those aged 61 years or older. However, people aged 46–60 years and those aged 61 years or older were not different in the use of private providers.

Regarding income, people in Q3 and Q4 were 1.30 and 2.17 times more likely to use private providers than those in Q1. However, the use of private providers was not different between people in Q2 and Q1. In terms of education and marital status, people who were highly educated and those who were married had a 1.71 and 1.60 times higher use of private providers than those who had a low education level and those who were single, respectively. Moreover, urban residents had a 1.22 times higher use of private providers than rural residents. Lastly, beneficiaries with a chronic disease were 2.77 times more likely to use private providers than those without a chronic disease.

In summary, consistent with the descriptive analysis results, the MLR results indicated that non-users of the UCS (both self-medication and private-provider users) generally had high socio-demographic status compared to UCS users. The common factors for the use of self-medication and private providers were a young age, high income, employment, urban residency, and the absence of a chronic disease.

3.3 Reasons for non-use of the UCS

The results regarding reasons for not using the UCS are revealed in Table 3. Among a total of 2,598 beneficiaries using private healthcare, 1,566 were missing values and 91 were unidentified values, such as "others" and "unknown." After eliminating these missing and unidentified values, 941 beneficiaries were ultimately used for analysis.

Among the 941 non-users of the UCS, the most frequently reported reason for not using the UCS was accessibility barriers (59.6%), followed by availability (25.4%) and quality barriers (14%). Specifically, among the accessibility barriers, long queue in designated providers (53.9%) and long distance to designated providers (5.4%) were the main reasons. Among the availability barriers, the limited service hours of designated providers (16.6%) and limited healthcare benefits of the UCS (7.2%) were the main reasons. Among the quality barriers, unsureness about medicine quality (8.5%) and inaccurate diagnosis and ineffective treatment (5.5%) were the main reasons.

This pattern was consistent for both self-medication and private-provider users. However, an interesting difference was noticed between these two groups. Specifically, although the percentage of respondents who cited accessibility barriers was similar between self-medication (58.9%) and private-provider users (60.1%), the percentage of respondents who cited availability barriers was higher in self-medication users (30.1%) than in private-provider users (22.3%). Meanwhile, the percentage of respondents who cited quality barriers was higher in private-provider users (16.5%) than in self-medication users (10.2%).

In summary, the most common reason for not using the UCS was accessibility barriers (59.6%, e.g., long wait time), followed by availability (25.4%, e.g., limited service hours) and quality barriers (14%, e.g., unsureness of medicine quality), for both self-medication and private-provider users. Moreover, self-medication users tended to be concerned about availability issues, while private-provider users tended to be concerned about quality issues when using the UCS.

TABLE 2 Results of multinomial logistic regression analysis.

Variables	Self-medication (vs. UCS)				Private provider (vs. UCS)			
	AOR	95% CI	*p*-value	VIF	AOR	95% CI	*p*-value	VIF
Predisposing factor								
Age								
15–30	1.53	(1.11, 2.11)	0.010	1.917	1.82	(1.20, 2.76)	0.005	1.865
31–45	1.36	(1.08, 1.73)	0.038	1.693	1.44	(1.06, 1.97)	0.042	1.620
46–60	1.14	(0.96, 1.35)	0.145	1.524	1.01	(0.80, 1.27)	0.930	1.462
61 or older	1.00				1.00			
Sex								
Male	1.01	(0.88, 1.16)	0.870	1.083	0.91	(0.76, 1.09)	0.319	1.086
Female	1.00				1.00			
Enabling factor								
Income								
Q2	1.59	(1.35, 1.88)	<0.001	1.287	1.15	(0.91, 1.44)	0.238	1.236
Q3	1.56	(1.31, 1.86)	<0.001	1.313	1.30	(1.02, 1.65)	0.031	1.248
Q4	2.11	(1.70, 2.62)	<0.001	1.297	2.17	(1.66, 2.83)	<0.001	1.249
Q1	1.00				1.00			
Education								
Middle	0.92	(0.76, 1.11)	0.390	1.491	1.18	(0.93, 1.51)	0.181	1.513
High	0.85	(0.57, 1.27)	0.423	1.120	1.71	(1.09, 2.68)	0.019	1.147
Low	1.00				1.00			
Marital status								
Married	1.11	(0.87, 1.42)	0.388	2.740	1.60	(1.15, 2.22)	0.005	3.061
Divorced	1.19	(0.91, 1.57)	0.208	2.906	1.21	(0.83, 1.77)	0.329	3.194
Single	1.00				1.00			
Employment								
Yes	1.38	(1.18, 1.61)	<0.001	1.455	1.37	(1.11, 1.68)	0.003	1.428
No	1.00				1.00			
Place of residence								
Urban	1.17	(1.03, 1.34)	0.017	1.040	1.22	(1.02, 1.45)	0.046	1.037
Rural	1.00				1.00			
Need-for-care factor								
Chronic disease								
No	6.84	(5.93, 7.88)	<0.001	1.229	2.77	(2.30, 3.34)	<0.001	1.202
Yes	1.00				1.00			
Pearson's GOF test								
Chi-square (DF)	1,749.290 (1,788)							
p-value	0.739							

AOR, adjusted odds ratio; CI, confidence interval; VIF, variance inflation factor; GOF, goodness-of-fit; DF, degrees of freedom.

4 Discussion

Although the UCS has increased overall healthcare use by offering free healthcare since it began in 2002, a significant number of beneficiaries have continued to depend on private healthcare. This resultant low use of the UCS has been cited as a challenge to achieving the policy's objective of universal access to healthcare. Thus, this study divided healthcare use into three patterns (self-medication, private providers, and UCS) and investigated the socio-demographic characteristics of non-users of the UCS and their reasons for non-use.

The results reveal that about 46.1% of UCS beneficiaries using healthcare services used them outside the UCS delivery system. Among them, about 33.8 and 12.3% used self-medication and private healthcare providers, respectively. The non-users generally had a

TABLE 3 Reasons for non-use of the UCS.

Reasons for non-use of the UCS	Overall (*n* = 941; 100%)		Self-medication (*n* = 372; 39.5%)		Private provider (*n* = 569; 60.5%)	
	n	%	*n*	%	*n*	%
Availability barriers						
Limited service hours of designated provider	156	16.6	72	19.4	84	14.8
No designated provider in my place of residence	15	1.6	9	2.4	6	1.1
Limited healthcare benefits of the UCS	68	7.2	31	8.3	37	6.5
Subtotal	239	25.4	112	30.1	127	22.3
Accessibility barriers						
Long distance to designated provider	51	5.4	23	6.2	28	4.9
No transportation options to designated provider	3	0.3	2	0.5	1	0.2
Long queue in designated provider	507	53.9	194	52.2	313	55.0
Subtotal	561	59.6	219	58.9	342	60.1
Acceptability barriers						
Discrimination	1	0.1	1	0.3		
Unfriendly doctors or nurses	8	0.9	2	0.5	6	1.1
Subtotal	9	1.0	3	0.8	6	1.1
Quality barriers						
Unsureness of medicine quality	80	8.5	22	5.9	58	10.2
Inaccurate diagnosis and ineffective treatment	52	5.5	16	4.3	36	6.3
Subtotal	132	14.0	38	10.2	94	16.5
Total	941	100	372	100	569	100

higher socio-demographic status than the UCS users. Specifically, they were young, had a high income, were employed, lived in urban areas, or did not have a chronic disease. The most common reason for the non-use of the UCS was accessibility barriers (59.6%; e.g., long queues in public providers), followed by availability (25.4%; e.g., limited operating hours of public providers), and quality barriers (14%; e.g., unsureness about the quality of medicine given by public providers). Moreover, self-medication users tended to be concerned about availability barriers, while private-provider users tended to be concerned about quality barriers to using the UCS.

The results, especially those regarding the non-use rate of the UCS and associated socio-demographic patterns, were consistent with those from previous studies in Thailand (11–13). Moreover, this study explored reasons for the non-use of the UCS according to four components suggested by the WHO's AAAQ framework (24, 25). In doing so, this study could assess specific barriers to the use of the UCS by patterns of healthcare use, which have been understudied in previous studies in Thailand.

The present results imply that access to healthcare is a multi-dimensional concept containing various sub-elements as indicated by the WHO's AAAQ framework. Accordingly, universal access to healthcare cannot be accomplished by lowering financial barriers to healthcare use alone. Instead, it also relies on how multiple elements are considered and improved together.

Specifically, the UCS could be considered an insurance policy that increases financial accessibility (i.e., free healthcare in designated providers). This could increase healthcare use by low socio-demographic groups, who generally cannot afford healthcare, as shown in this study. However, the policy may not yet be able to increase other elements, such as availability and physical accessibility elements, which are related to healthcare resources and infrastructure. This may have caused the UCS to create situations that could not serve the demands of beneficiaries, especially those in high socio-economic groups (e.g., long queues in designated providers), and ultimately forced them to use private healthcare.

This discussion above is supported by several empirical studies in Thailand (28, 29). For instance, an observational study conducted by NaRanong and NaRanong found that after the UCS was introduced, public providers were greatly congested and understaffed, which led to issues for UCS beneficiaries, such as long queues and insufficient physician consultation times. The issues tended to push some beneficiaries who previously used public healthcare providers—especially those with severe illnesses, time constraints, or a high socio-demographic status—into the private healthcare sector (28).

Therefore, the government should make efforts to enhance the use of the UCS to accomplish the policy's objective. This study recommends specific policy measures based on the results and discussions.

First, regarding accessibility barriers, particularly long queues, to public provider use, the workforce of the primary healthcare system should be strengthened. In Thailand, there are 77 provinces with 878 districts. Each province and district has one or two major provincial-and district-level hospitals, along with a number of sub-district-level healthcare centers. In 2016, there were 156 provincial-level hospitals, 780 district-level hospitals, and 9,579 sub-district-level healthcare centers (30, 31).

However, sub-district healthcare centers, which are a main component of the primary healthcare system, are staffed by two or three nurses and trained healthcare volunteers rather than physicians, except for some representative healthcare centers in each administrative area. Since these centers offer only basic healthcare services, beneficiaries demanding complex healthcare are generally referred to district-and provincial-level hospitals (31). This could have been the main cause of long queues for public providers. Thus, the government should strengthen the workforce of the primary healthcare system by increasing the number of representative centers and assigning more physicians to centers to alleviate the issue of long queues for designated providers.

Second, in terms of availability barriers, especially the restricted operating hours of designated providers (from 9:00 a.m. to 5:00 p.m.), previous studies have consistently reported that beneficiaries who have time constraints, such as employed people, generally depend on private healthcare (11–13, 20). To resolve this issue, the flexibility of the service hours of public providers needs to be increased by identifying people's healthcare needs after operating hours. The UCS also requires cooperation with private providers to, for example, cover a certain portion of the after-service-hours healthcare offered by private providers.

Third, regarding quality barriers, a general perception that the quality of private healthcare (or private providers) is better than that of public healthcare (or public providers) is widespread in Thailand. The government should change the perception through diverse public relations activities, such as public campaigns and education programs.

Although we recommend specific policy measures based on the key results of the study, these recommendations should be short-term measures. In the long term, the government must continue its endeavors to address the current lack and geographical imbalance of healthcare resources and infrastructure in the public sectors and the low involvement of private healthcare providers in the UCS policy, as these factors are well-known to hamper the use of the UCS in Thailand (1, 2, 30, 31).

This study includes limitations that must be considered in future studies. First, the 2019 HWS asked respondents to select only one main place where they received healthcare services; thus, this study did not consider individuals who received healthcare services from different places at the same time (e.g., UCS and self-medication or UCS and private providers). Likewise, respondents were asked to select only one primary reason for not using the UCS. However, UCS beneficiaries may have encountered multiple barriers simultaneously. For instance, long queues and long distances may be direct barriers, while quality issues may be indirect barriers. Moreover, since a significant number of respondents did not answer or gave an undefined answer to the question, we had to use only limited samples to analyze reasons for the non-use of the UCS. Due to these issues, the study results may include over-or under-generalization issues. The National Statistical Office of Thailand must consider these issues for future HWSs. Addressing this limitation, especially the issue of missing or unidentified answers would allow future studies to explore reasons for the non-use of the UCS according to different socio-demographic groups so that policy measures can be modified accordingly.

Second, this study simplified the pattern of healthcare use into three categories (i.e., self-medication, private providers, and UCS). Such simplistic categorization might not accurately capture the policy impact. Specifically, regarding self-medication, we combined over-the-counter drugs and Thai traditional medicines. However, some Thai traditional medicines are covered by the UCS and are available in large provincial-and district-level hospitals (13). Additionally, there may be a possibility that some beneficiaries may have visited pharmacies to receive prescription medicines that are covered by the UCS.

Regarding private providers, some beneficiaries may have received healthcare services from UCS-contracted private providers, though these contracted providers cover only 5.7% of all UCS beneficiaries (13). However, the 2019 HWS did not provide related information in detail; accordingly, this study ultimately adopted the same categorization method employed in previous studies (11–13), which should also be considered by the National Statistical Office for future HWSs.

Third, the pattern of healthcare use relies generally on disease severity (32, 33). However, since the 2019 HWS did not include clinical factors, such as disease severity, this study did not control for them in the analysis. Particularly regarding self-medication, previous studies showed that the main reasons for using self-medication included mild symptoms, time-saving, convenient accessibility, and a scarcity of physicians (34–36). These results are partly consistent with our study's results that UCS beneficiaries used self-medication primarily due to long queues and limited service hours of public providers. Nevertheless, future studies should consider adjusting for clinical factors including disease severity in analysis to make more precise evaluations of the policy's effects on the pattern of healthcare use. Combining the HWS with other clinical data such as medical claims or hospital management data can help overcome this limitation.

Fourth, the study's outcome variable (patterns of healthcare use) was measured by using self-reported data, with respondents directed to evaluate their healthcare needs by their perceptions. Thus, they should be aware of their healthcare needs and also be willing to report them. Such subjective measure unavoidably comprises recall bias and social desirability bias issues (37, 38); thus, this study's results must be interpreted by considering this issue.

Lastly, the validity and reliability of the cross-sectional pattern of healthcare use found in this study should be examined in a longitudinal study. In addition, this study recommends that the government set the non-use of the UCS as a policy assessment indicator and establish a regular-basis monitoring system accordingly.

5 Conclusion

The results of the present study imply that healthcare access is a multi-dimensional concept containing diverse sub-elements, such as physical and financial accessibility of healthcare. Accordingly, universal access to healthcare cannot be readily accomplished by lowering financial barriers to healthcare use alone. Instead, it also relies on how multiple elements are considered and improved together.

In the case of the UCS, among the elements, the lack of healthcare resources and infrastructure in the public sectors was the most important issue in accomplishing its goal of universal access to healthcare. The UCS has increased financial accessibility for the use of the UCS (i.e., free healthcare from public providers). However, it probably has not yet increased healthcare resources and infrastructure facilitating the use of the UCS. This may have caused the UCS to create situations that could not serve the demands of beneficiaries, especially

those in high socio-economic groups (e.g., long queues in public providers and limited service hours of public providers), and ultimately forced them to use private healthcare. Therefore, the government should continue its endeavors to invest in healthcare resources and infrastructure in the public sectors to increase the use of the UCS.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found: the 2019 dataset used in the present study is available from the authors upon reasonable request and with the permission of the National Statistical Office of Thailand. Requests to access the dataset should be directed to SCP, seungchun.pak@mahidol.ac.th.

Ethics statement

This study was approved for "Exemptions from IRB review" by the Office of The Committee for Research Ethics in the Faculty of Social Sciences and Humanities, Mahidol University (Certificate of Exemption No. 2024/008.3007).

Author contributions

SCP: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. NZ: Conceptualization, Investigation, Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix

TABLE A1 Complete results of multinomial logistic regression analysis.

Variables	Self-medication (vs. UCS)							Private provider (vs. UCS)						
	COR	95% CI	*p*-value	AOR	95% CI	*p*-value	VIF	COR	95% CI	*p*-value	AOR	95% CI	*p*-value	VIF
Predisposing factor														
Age														
15–30	3.95	(3.15, 4.94)	<0.001	1.53	(1.11, 2.11)	0.010	1.917	3.47	(2.57, 4.68)	<0.001	1.82	(1.20, 2.76)	0.005	1.865
31–45	3.30	(2.76, 3.94)	<0.001	1.36	(1.08, 1.73)	0.038	1.693	3.10	(2.44, 3.95)	<0.001	1.44	(1.06, 1.97)	0.042	1.620
46–60	1.99	(1.74, 2.28)	<0.001	1.14	(0.96, 1.35)	0.145	1.524	1.64	(1.34, 1.99)	<0.001	1.01	(0.80, 1.27)	0.930	1.462
61 or older	1.00			1.00				1.00			1.00			
Sex														
Male	1.15	(1.02, 1.29)	0.023	1.01	(0.88, 1.16)	0.870	1.083	1.05	(0.89, 1.24)	0.573	0.91	(0.76, 1.09)	0.319	1.086
Female	1.00			1.00				1.00			1.00			
Enabling factor														
Income														
Q2	1.71	(1.48, 1.98)	<0.001	1.59	(1.35, 1.88)	<0.001	1.287	1.30	(1.05, 1.62)	0.019	1.15	(0.91, 1.44)	0.238	1.236
Q3	1.92	(1.64, 2.24)	<0.001	1.56	(1.31, 1.86)	<0.001	1.313	1.67	(1.33, 2.09)	<0.001	1.30	(1.02, 1.65)	0.031	1.248
Q4	2.50	(2.08, 3.01)	<0.001	2.11	(1.70, 2.62)	<0.001	1.297	2.87	(2.25, 3.66)	<0.001	2.17	(1.66, 2.83)	<0.001	1.249
Q1	1.00			1.00				1.00			1.00			
Education														
Middle	2.00	(1.74, 2.31)	<0.001	0.92	(0.76, 1.11)	0.390	1.491	2.21	(1.82, 2.69)	<0.001	1.18	(0.93, 1.51)	0.181	1.513
High	1.93	(1.37, 2.73)	<0.001	0.85	(0.57, 1.27)	0.423	1.120	3.45	(2.32, 5.15)	<0.001	1.71	(1.09, 2.68)	0.019	1.147
Low	1.00			1.00				1.00			1.00			
Marital status														
Married	0.68	(0.57, 0.82)	<0.001	1.11	(0.87, 1.42)	0.388	2.740	0.90	(0.69, 1.17)	0.418	1.60	(1.15, 2.22)	0.005	3.061
Divorced	0.46	(0.38, 0.56)	<0.001	1.19	(0.91, 1.57)	0.208	2.906	0.48	(0.35, 0.65)	<0.001	1.21	(0.83, 1.77)	0.329	3.194
Single	1.00			1.00				1.00			1.00			
Employment														
Yes	2.27	(2.01, 2.55)	<0.001	1.38	(1.18, 1.61)	<0.001	1.455	2.02	(1.70, 2.40)	<0.001	1.37	(1.11, 1.68)	0.003	1.428
No	1.00			1.00				1.00			1.00			
Place of residence														
Urban	1.17	(1.04, 1.31)	0.008	1.17	(1.03, 1.34)	0.017	1.040	1.12	(0.95, 1.32)	0.186	1.22	(1.02, 1.45)	0.046	1.037
Rural	1.00			1.00				1.00			1.00			
Need-for-care factor														
Chronic disease														
No	7.81	(6.85, 8.90)	<0.001	6.84	(5.93, 7.88)	<0.001	1.229	3.47	(2.93, 4.12)	<0.001	2.77	(2.30, 3.34)	<0.001	1.202
Yes	1.00			1.00				1.00			1.00			
Pearson's GOF test														
Chi-square (DF)	1,749.290 (1,788)													
p-value	0.739													

COR and AOR, crude and adjusted odds ratio; CI, confidence interval; VIF, variance inflation factor; GOF, goodness-of-fit; DF, degrees of freedom.

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Female and male treatable mortality: socioeconomic and public finance related factors across European countries

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Background: About 36.5% of premature deaths in European Union countries could have been avoided through prompt and effective medical treatment. This treatable mortality is even a priority established in Sustainable Development Goal (SDG) target 3.4. Given the gap in the literature about the socioeconomic drivers of this type of mortality, as well as the increasing importance of public financial management in defining priority policies, this study aims to analyze the socioeconomic and public finance drivers associated with treatable mortality for women and men across European countries.

Methods: Eurostat data is collected for 31 countries for the period 2011–2019 stratified by sex. Panel data quantile regression with fixed effects and conditional mean panel data model using feasible generalized least squares are estimated to explain treatable mortality in women and men.

Results: Key findings point to a positive association between the public finance indicator proxying health priority and the treatable mortality rate for both sexes; a difference between drivers of treatable mortality between men and women; and a different set of drivers across the different quantiles of treatable mortality.

Conclusion: Drivers of male and female treatable mortality may differ according to the country's level of mortality rate. Government health priority seems to account for previous treatable mortality rates as a reactive measure. Policymakers aiming to reduce treatable mortality are likely to use instruments such as health expenditure, improved employment, education levels, and perhaps proactive policy-setting priorities concerning health.

KEYWORDS

treatable mortality, socioeconomic factors, public finance, Europe, quantile regression

Introduction

The European Union (EU) witnessed premature deaths of 1,015,225 individuals under the age of 75 prior to the COVID-19 pandemic in 2019. Of these fatalities, approximately 36.5% (a total of 371,570 people) could have been prevented through prompt and effective medical treatment. The incidence of preventable death is notably higher among men, accounting for approximately 56% of cases and 44% among women.

Treatable mortality refers to deaths that could have been prevented through timely and effective healthcare interventions, including secondary prevention and treatment, following

the onset of a disease, with the primary aim of reducing case fatality. The leading causes of this type of death are ischaemic heart disease, colorectal cancer, cerebrovascular disease, and breast cancer in women (1). This measure serves as a valuable indicator of health care system efficacy and as an indicator of economic development. Its importance has been magnified and given greater priority by policymakers in the implementation of Sustainable Development Goal (SDG) target 3.4. This target explicitly aims to reduce premature mortality resulting from non-communicable diseases to foster mental health and well-being, because low-quality health systems are related with high mortality rates (2). Moreover, premature mortality represents capital losses and GDP losses, thus justifying the promotion of high-quality healthcare under universal health coverage and of socioeconomic determinants of health (3).

Conceptual clarification may be necessary at this stage. Treatable mortality is a component of premature or avoidable mortality, as defined by Eurostat (4). The other component is preventable mortality, which also refers to deaths before the age of 75; however, it includes the causes of death that can be mainly avoided through effective public health and primary prevention interventions. These causes include some infectious diseases (e.g., HIV/AIDS), some forms of cancer (e.g., lung cancer), some respiratory diseases (e.g., influenza), injuries, and alcohol-and drug-related disorders (1). The difference between treatable and preventable mortality is related to the moment that healthcare intervention could have occurred. While preventable mortality refers to public health intervention before the onset of a disease or injury, treatable mortality refers to public health intervention after disease onset. Here, the focus is on treatable mortality.

The objective of this study is to examine the socioeconomic and public finance drivers associated with treatable mortality for women and men across European countries for the period 2011–2019 (it does not aim to explain sex differences). To accomplish this, we estimate a fixed effects panel data linear model and quantile panel data linear regression with country controls stratified by sex for EU countries. This study addresses a gap in the existing literature about the drivers of treatable mortality, particularly public finance drivers, and contributes to understanding the underlying trends that account for variations in this health outcome indicator across European countries (Figure 1). In fact, recently at the iHEA World Congress, it was concluded that despite the strong theoretical link between public financial management and health, the empirical evidence is weak (5).

The socioeconomic determinants of health outcomes (6) have been thoroughly analyzed and discussed by several authors (7–11). An extensive review (12) lists the most important socioeconomic variables according to their statistical performance for predicting mortality, such as economic inequality, social welfare, economic performance, unemployment, and material deprivation. A small set of studies are worth mentioning because of their valuable contribution to the literature based on the estimation of panel data models (10, 13–19) (Supplementary Table S10). Although all studies include GDP *per capita* and health expenditures as independent variables, none include variables that capture the influence of public finance, specifically two indicators proposed by Kutzin (20), fiscal capacity and health priority setting with respect to the allocation of public resources. These two indicators are, respectively, proxied by the percentage of general government spending in GDP and by general government health spending (where expenditure resulting from taxes and from compulsory social insurance contributions is to be included) in general government spending. Although fiscal capacity is more subject to macroeconomic conditions on which the government may have less influence in the short-run, such as increasing tax revenues, health priority is less subject to these macro-contextual factors and more likely to be influenced by government choices in the short-run.

Materials and methods

Data and variables

The data utilized in this analysis was sourced from the Eurostat database (21), covering a span from 2011 to 2019, encompassing 31 European countries (Supplementary Table S1).

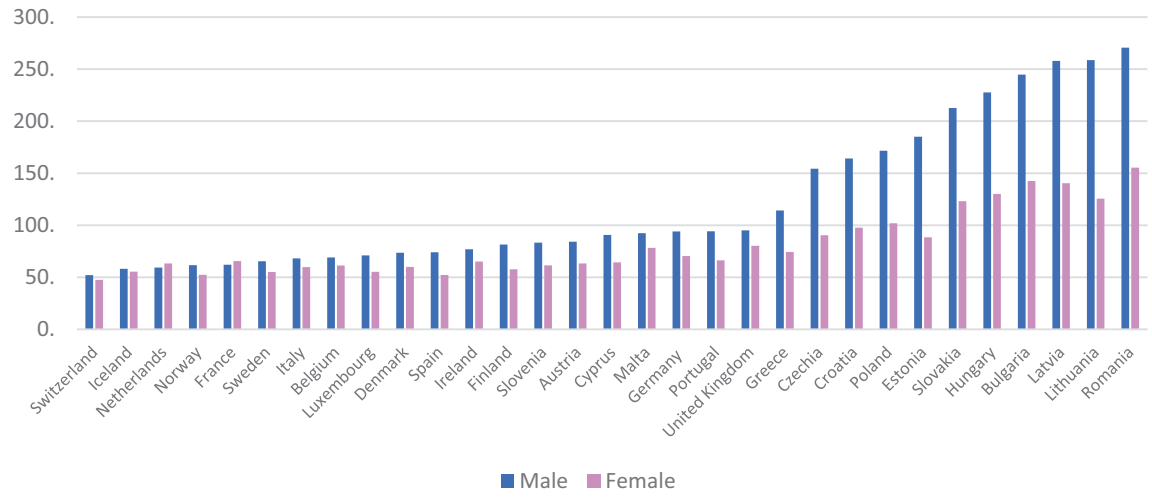


FIGURE 1
Treatable mortality in EU countries, 2019. Source: Eurostat [online code hlth_cd_apr] (21).

Dependent variable

For this analysis, the dependent variable employed is the yearly standardized rate of treatable mortality among residents younger than 75, stratified by gender [online code 'HLTH_CD_APR'].

Independent variables

The explanatory variables, abbreviation, description, and Eurostat online code are shown in Table 1. This set of variables includes several macroeconomic controls, including two variables capturing the public finance features, meaning the fiscal capacity and governmental priority for health.

Quantitative analysis

First, we present a descriptive analysis of the variables and display the pairwise correlation between all the variables. Then we undertake some preliminary tests: (i) a Silk-Wilkson test for normal distribution of variables; (ii) a VIF estimation to check for multicollinearity; (iii) Cook's distance to check for outliers and influential data; (iv) a Hausman test to compare fixed or random effects.

Finally, we obtain quantile plots for treatable mortality, and we estimate a quantile regression with fixed effects (22). Additionally, conditional mean panel data regression with fixed effects for women and men is estimated, as well as a panel data model using feasible generalized least squares (FGLS) to check robustness. A post-estimation Wald test is performed which allows the evaluation of the global significance of the estimated models. The analysis is performed in STATA 16.

Results

The descriptive statistics for the panel data and pairwise correlations between variables are, respectively, presented in Supplementary Tables S2, S3. Despite some moderate level of correlations within the interval 0.5–0.7, there is no multicollinearity as displayed in Supplementary Table S4. The Cook's distance score is below 1, indicating the absence of outliers for the male and female samples. The Shapiro–Wilk test for normal data is displayed in Supplementary Table S5. The descriptive statistics for treatable mortality rate across the whole data for males and females is presented in Table 2.

The quantile plots can be found in Supplementary Figures S1, S2. Accordingly, it can be seen that in general female data are smooth, meaning there is no jump in data, while for male data there is a clear jump at about 70% of the fraction of treatable mortality data. For this reason, the quantiles used to estimate the quantile regression are the 30th, 50th, and 70th, used for both sexes for the sake of comparison. The statistics description by deciles of treatable mortality rate are presented in Supplementary Table S6. For instance, the 30th percentile takes the value 82.83 for males mortality rate, while for women it takes the value 66.05.

The Hausman test indicates the existence of fixed effects for the female samples but for the male sample, we may accept fixed effects with a statistical significance level of 0.0756. For this reason, we present the estimation of fixed effects and random effects for the male sample. The results for the panel data regressions based on the conditional mean are presented in Supplementary Table S7. Additionally, the estimation of the panel-data models using feasible generalized least squares is presented in Supplementary Table S8.

In general, the results show that there are more statistically significant drivers for men than for women. For both men and women, GDP, health expenditure, both public/compulsory and OOP expenditure, and education contribute to the decrease of treatable mortality. Also, for both samples, government health priority has a positive association with the treatable mortality rate, though in some instances the *p*-value is between 0.5 and 0.8. What distinguishes the results between women and men is the statistically significant role of variables related to socioeconomic inequalities. For men, unemployment tends to increase the rate of treatable mortality; on the other hand, risk of poverty (for the feasible generalized least squares

TABLE 1 Description of independent variables.

Variable	Abbreviation	Description	Eurostat online code
GDP *per capita*	GDPpc	Natural logarithm of purchasing power adjusted GDP *per capita*.	SDG_10_10
Public health expenditures	PHE	Government schemes and compulsory contributory health care financing schemes as percentage of GDP.	HLTH_SHA11_HF
Out-of-pocket payments	OOP	Out-of-pocket expenditure as a percentage of current health expenditure.	HLTH_SHA11_HF
Fiscal_Capacity	Fiscal_Cap	Total general government expenditure as a percentage of GDP.	GOV_10A_EXP
Priority_Health	Prior_Health	Government health expenditure as percentage of total general government expenditure.	GOV_10A_EXP
Education m/f	Education	Population by educational attainment level, Tertiary education (levels 5–8), percentage of people from 15 to 64 years.	EDAT_LFSE_03
Unemployment m/f	Unemploym	Unemployment as percentage of population in the labour force.	UNE_RT_A
Risk poverty or social exclusion m/f	Risk_Pov	Persons at risk of poverty or social exclusion percentage of population.	ILC_PEPS01
Unmet healthcare needs m/f	Unmet_HN	Self-reported unmet needs for medical examination, too expensive or too far to travel or waiting list, percentage population aged over 16 years.	HLTH_SILC_08

m, male; f, female.

TABLE 2 Treatable mortality rate overall description statistics.

	Mean	Std. Dev.	Min	Max
Males	132.92	73.97	52.02	333.31
Females	88.15	32.88	47.54	177.74

estimation) and unmet health care needs have also a positive association with mortality.

Lastly, the quantile panel data regressions are presented in Table 3. Concerning these results and firstly, as expected variables GDP *per capita* and Health expenditure are statistically significant variables that contribute to reducing the mortality rate across all quantiles of the distribution. Fiscal_Cap is never statistically significant across all quantiles.

Second, for lower levels of treatable mortality, the 30th quantile, statistically significant independent variables exist for the male sample other than GDP and PHE. However, the signs found for Risk_poverty and Unmet_HN show a negative correlation, whereas for the variable Health_priority there is a positive correlation.

At the 50th quantile of treatable mortality, the regression of females presents other statistically significant variables: Health expenditure, OOP, Health_Prior, and Education. For males, there are two additional significant variables: Unemploym and Unmet_HN, which maintain the negative correlation. For both men and women, we found a positive association between health priority and treatable mortality.

Finally, for the 70th quantile, the results for women are identical to those obtained for the 50th quantile while for men the variable Unmet_HN loses statistical significance.

TABLE 3 Quantile panel data regressions.

	Males		Females	
0.3 Quantile regression	**Coef.**	***P* > *z***	**Coef.**	***P* > *z***
GDPpc	−72.761	<0.001	−48.729	<0.001
PHE	−6.710	0.001	−3.667	0.033
OOP	−0.587	0.274	−0.517	0.091
Fiscal_cap	−0.131	0.719	−0.110	0.683
Prior_Health	2.012	0.045	0.747	0.298
Education	−0.788	0.008	−0.199	0.269
Unemploym	0.623	0.063	0.204	0.382
Risk_Pov	−0.652	0.049	−0.132	0.606
Unmet_HN	−1.181	0.007	−0.361	0.134
0.5 Quantile regression				
GDPpc	−65.827	<0.001	−48.395	<0.001
PHE	−6.836	<0.001	−4.270	0.002
OOP	−0.743	0.114	−0.486	0.051
Fiscal_cap	−0.051	0.873	−0.029	0.894
Prior_Health	2.214	0.012	1.259	0.033
Education	−0.944	<0.001	−0.291	0.048
Unemploym	0.697	0.018	0.244	0.199
Risk_Pov	−0.500	0.086	−0.119	0.566
Unmet_HN	−1.089	0.004	−0.260	0.187
0.7 Quantile regression				
GDPpc	−54.249	<0.001	−47.953	<0.001
PHE	−7.047	0.006	−5.066	0.007
OOP	−1.003	0.140	−0.446	0.186
Fiscal_cap	0.083	0.858	0.078	0.793
Prior_Health	2.552	0.045	1.935	0.014
Education	−1.204	0.001	−0.413	0.037
Unemploym	0.819	0.054	0.296	0.248
Risk_Pov	−0.247	0.556	−0.103	0.714
Unmet_HN	−0.937	0.091	−0.126	0.635
Number of obs = 251				

Discussion

This study reveals that public health prioritization is, in general, positively associated with treatable mortality rates, whereas no evidence was found in previous studies concerning fiscal capacity. Additionally, the drivers of treatable mortality differ by gender, and these drivers vary across quantiles, indicating that factors affecting mortality rates differ depending on the level of mortality.

First, results obtained from different estimation techniques showed a positive association between the public finance indicator, that proxy health priority, and treatable mortality rate for both sexes. This is, to some extent, an unexpected correlation as one would associate higher public health priority with better health outcomes and lower treatable mortality. This could be explained by potential inefficiencies in the allocation of public funds that do not necessarily improve health outcomes. These inefficiencies could arise from mismanagement, failed targeted public health interventions, or other systematic healthcare delivery issues.

However, it could be argued that the positive correlation found here expresses the relationship between public health expenditure levels decided following the observed levels of treatable mortality. That is, a government decides on health priority for year N + 1, based on the observed treatable mortality rate in year N. Therefore, increasing levels of treatable mortality will be associated with higher levels of health priority, not only because there is a public health problem to be addressed but also for political cycle reasons.

Unfortunately, we have not found another empirical study using the same public finance variables and time series available is too short to allow for a causality analysis. However, close to our finding, Berger and Messer (23) found that increasing all causes of mortality rate was associated with increasing public (excluding mandatory social contributions) expenditure as a share of total health expenditures, but no dynamic or causal analysis was performed by those authors.

Concerning fiscal capacity, we did not find any statistical evidence to support a correlation with treatable mortality. One may expect this to happen, as this indicator is better suited for long time series analysis because government's influence over it is usually small and sluggish. On the other hand, it could also be that this indicator is not directly related with public health decisions and its effects on health outcomes.

In this way, broader fiscal capacity alone seems to be insufficient to influence directly treatable mortality without efficient and targeted health expenditure (24). Although no previous study uses this indicator and relates it to some health outcome indicator, if we consider that low fiscal capacity may be related to a country's high indebtedness, then debt results in a deterioration of health outcome indicators in the long run (25), in line with the much earlier proposal, in 1986, by Sell and Kunitz (26).

Second, findings point to a difference between the drivers of male and female treatable mortality. In general, women seem less influenced by inequality in socioeconomic factors, except for education, whereas men seem to be more susceptible to the influences of socioeconomic status such as unemployment, the risk of poverty or social exclusion, and unmet healthcare needs.

Common drivers of female and male treatable mortality are GDP *per capita* and public health expenditure. These associations were expected and are in line with the results reported in the literature (10, 13–17, 19, 27–31). Higher GDP *per capita* and higher public health expenditures are associated with better health outcomes, including lower treatable mortality. A higher GDP *per capita* reflects greater economic resources available for both individuals and governments. Larger financial resources for individuals allow them to access better living conditions and better healthcare quality; larger public health expenditures finance more investment needed to enhance healthcare infrastructure and improve healthcare interventions. Nevertheless, causal links between lower mortality and higher public health expenditures are seldom established (29), and the mechanisms and quality of public financial management are not well-understood (30).

Another common driver for women and men is education. The relationship between higher education levels and better health outcomes is well-known (32, 33). Concerning socioeconomic drivers, treatable mortality among men is associated with unemployment, and we did not find evidence that this affects women. This result is recognized elsewhere (14, 34, 35). Results also indicate a negative association between risk of poverty and treatable mortality and between unmet healthcare needs and treatable mortality. These two results are unexpected and seem to indicate the apparently wrong direction of the correlation. One expects that people affected by poverty have limited access to factors that foster good health, such as nutrition and healthy foods, shelter, safe neighborhoods in which to learn, live and work, clean air and water; thus, they would be more likely to experience illness (10, 36, 37). Our findings point in the opposite direction, which is in line with Jorgensen et al. (38) for Norway. However, a careful analysis of this result may indicate the existence of social policies to improve living conditions and access to healthcare for people at risk of poverty or social exclusion, especially in countries with higher GDP *per capita*. In fact, observing the scatter plot between male mortality and male risk of poverty (Supplementary Figure S3) and considering the pairwise correlation of −0.67, it is clear that risk of poverty is associated the higher mortality. However, when accounting for the influence of GDP *per capita*, the sign of the association changes (Supplementary Table S9), indicating the potential existence of other variables influencing the relationship between risk of poverty and treatable mortality.

An identical interpretation can be applied to the results regarding the negative association between unmet healthcare needs and treatable mortality in males. One would expect unmet health care needs would lead to poorer health outcomes and eventually to premature mortality (39). Our result is in the same direction as Lindstrom et al. (40), who found that for the age group 18–64 years there was no significant association between unmet healthcare needs and mortality. However, when controlling for GDP *per capita*, the negative effects of unmet healthcare needs are mitigated because of welfare policies in European countries are designed to lessen social inequalities. In fact, policies such as income support, and social insurance programmes contribute to reducing poverty, promoting housing access, and addressing other social determinants of health. These policies create a safety net that mitigates health disparities by fostering a more equitable distribution of health resources, and thus reducing treatable mortality rates (41).

Third, the findings show that depending on the level of mortality rate, different sets of drivers are active in women and men. Hence, no single recipe for all countries exists that aims to improve treatable mortality (42). Each country has its own sex inequality specific settings requiring specific policy measures. Nevertheless, some general trends may be established according to the level of mortality rate of each country.

For countries with lower values of treatable mortality among women, only two drivers play a role in mitigating this health outcome. These are GDP *per capita* and public health expenditures. For median or higher levels of female treatable mortality, a higher percentage of women with tertiary education also contributes to reduced mortality. Therefore, countries in Eastern Europe may use the instrument of education to improve women's health outcomes and prevent treatable mortality (14, 16).

There are several drivers associated with male mortality in countries with lower rates of mortality, and the size of this set of drivers decreases as the level of mortality rate increases. Therefore, for median rates of male mortality, unemployment is associated with mortality, education reduces it, and unmet health care needs are negatively associated with those deaths; and for higher rates of male mortality, while education decreases mortality, unemployment increases that death rate. For countries with higher rates of mortality (such as those captured by the 70th quantile and above), the only significant driver of treatable mortality that differs between men and women is unemployment, as some studies point to a larger effect of unemployment in men (43).

Conclusion

The study presented has three key findings. The first key finding is the positive association between the public finance indicator that proxy health priority and the treatable mortality rate for both sexes, except for women, when considering the lowest rates of mortality across countries. On the other hand, the indicator of fiscal capacity seems to be mute concerning the association with treatable mortality.

The second key finding is the difference in drivers of treatable mortality between men and women. For women, treatable mortality is generally explained by GDP *per capita*, health expenditures, education, and government health priority, whereas men's treatable mortality drivers also include socioeconomic indicators.

Finally, the last key finding concerns the different sets of drivers for treatable mortality across the different quantiles of treatable mortality; that is, statistically significant drivers differ across quantiles.

The drivers of male and female treatable mortality may differ according to the country's level of mortality rate. Government health priority defined within public financial management is positively associated with treatable mortality; this finding may suggest that government setting priorities accounts for previous treatable mortality rates as a reactive decision. Policymakers aiming to reduce treatable mortality are likely to use instruments like health expenditures, improve employment and education levels, and be proactive in setting priorities concerning health. The potential mechanisms underlying these instruments to reduce treatable mortality rates may work through several pathways. One pathway is increasing access to primary healthcare services, preventive care, early diagnosis and treatment via government expenditure. Another pathway is improving employment opportunities, which not only broadens access to healthcare, but also leads to better labor contracts that include health insurance. Lastly, rather than relying on reactive health policies focused on hospital care, proactive policies—such as vaccination and screening programs, health literacy initiatives, the promotion of healthier lifestyles, and workplace and traffic accident prevention campaigns—activate multiple pathways to achieve the desired health outcomes.

The analysis in this study has strengths and limitations. The major strength of this work is its contribution to the literature, for which there is a gap in terms of examining the socioeconomic determinants of treatable mortality rate for men and women. Additionally, it explores the association between public finance indicators and treatable mortality, which has not been explored previously and for which comparisons with other empirical evidence are not possible. There are some limitations that should be noted. First, the sample dataset is small; specifically, it considers a short period, thus, causality cannot be concluded. The results express associations or correlations between variables. Nevertheless, the analysis does yield clear and well-founded clues for policymakers regarding the relevance of public finance to health outcomes. Future work will extend the period of time to perform a causality analysis between public finance indicators and public health outcomes. Causality analysis between health outcomes and public finance indicators, including public health expenditures, is underexplored due to the complexity of isolating the direct effects of those indicators from other influencing factors like macroeconomic conditions, individual's lifestyles choices, and health system efficiency. Additionally, the time lag between any public expenditure and an observable health improvement, coupled with data limitations and methodological challenges, makes such analysis difficult to execute (41). Despite these difficulties, causal analysis allows for understanding how specific variables directly influence health outcomes, beyond correlation. For instance, it may allow researchers to determine whether an increase in public health expenditure directly improves treatable mortality rates or if observed improvements are due to other underlying factors such as socioeconomic conditions and healthcare delivery.

A second limitation relates to the public finance indicators used, as they do not capture the efficiency or equity of spending. Future research could address this by considering the cost-effectiveness of health expenditure by measuring changes in treatable mortality per additional monetary unit spent, and include indicators that reflect the distribution of health spending across lower socioeconomic groups to assess how well vulnerable populations are served. Nevertheless, the public finance indicators used in this investigation provide a solid measure of the overall fiscal orientation toward health and are also comparable across countries and over time.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: https://ec.europa.eu/eurostat/data/database.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1477402/full#supplementary-material

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Reimagining hospital management: the balanced scorecard as a catalyst for employee retention and organizational excellence

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Employee turnover in healthcare institutions is a critical issue affecting both quality of care and organizational costs. This study examines the potential impact of the Balanced Scorecard (BSC) as a communication tool on employee turnover rates in a Japanese hospital setting. A case study of Bethlehem Garden Hospital in Tokyo, Japan, was conducted to examine turnover rates before and after the implementation of BSC. The study also compares these rates to industry averages in Japan and the United States. The results show a significant reduction in turnover rates from 23.6% in 2015 to 3.4% in 2023 following the implementation of BSC, which is lower than both national and international industry averages. This reduction corresponded with increased employee engagement scores. The study suggests that the BSC when effectively implemented and communicated, can help reduce turnover by improving organizational alignment, employee engagement, and trust. Although the single case study design limits generalizability, these findings provide valuable insights into the potential of BSC as a strategic tool for addressing turnover in healthcare settings. Future research directions are suggested to validate these findings further in diverse healthcare environments.

KEYWORDS

balanced scorecard, hospital management, employee turnover, communication, engagement, healthcare workforce

1 Introduction

Decreasing turnover rates in healthcare institutions is an important issue worldwide (1). In particular, pandemics such as COVID-19 have increased the need to prevent turnover among healthcare workers (2). High hospital turnover leads to lower quality of care (3–5) and increased financial burden on hospitals (4–7). De Vries et al. (2) highlight that distinctive interventions consistent with mission, vision, and values are needed to improve the retention of healthcare workers. The Balanced Scorecard (BSC) is useful in addressing these issues. The BSC is a management and communication tool that communicates the mission, vision, values, and strategy (8, 9). Recently, studies have linked BSC as a corporate communication tool [e.g. (10–12)]. Corporate communication is one of the communication theories in organizations, and its purpose is to manage the relationship between the organization and its stakeholders (13).

Hospitals in Japan face increasing pressure to enhance their management practices. In other words, sustainable management is necessary. A June 2021 survey by the Japan Hospital

Federation (14) revealed that about 76.9% of the hospitals surveyed suffered from financial losses. The impacts caused by hospital deficits are manifold. Hospitals under financial pressure have a negative impact on the quality of care and patient safety (15). Dubas-Jakóbczyk et al. (16) discuss how physician shortages in Polish hospitals can severely impact hospital management. Hospital financial losses can make it difficult to improve physician salaries and benefits and can reduce the attractiveness of hospitals, for example, by forcing them to stop providing certain services due to a shortage of physicians. Thus, hospital deficits are a factor that affects not only hospitals but also patient health and community healthcare. BSC has emerged as a promising tool for hospital management in Japan in this challenging environment. Healthcare institutions widely adopt BSC to improve the quality of care (17, 18).

This paper focuses on turnover as an indicator of quality of care. Turnover rates in healthcare are an important indicator associated with quality of care and patient safety (4, 19–22). Several studies link BSC to turnover rates [e.g., (12, 23–25)]. However, only a few studies, such as Huang et al. (12), present data on reduced turnover.

Huang et al. (12) conducted a case study of BSC as a communication tool at Bethlehem Garden Hospital in Kiyose, Tokyo, Japan. The results showed that the implementation of BSC led to a decrease in turnover rates. However, the data presented here is limited to Bethlehem Garden Hospital and does not compare turnover rates with those of other hospitals in Japan or in the same industry.

This paper will focus on this Japanese data to provide additional insight into whether BSC can reduce turnover. Specifically, we will add data on turnover rates in the healthcare and welfare industries from Japan's Ministry of Health, Labour and Welfare (MHLW) and nursing staff turnover rates from the Japan Nursing Association (JNA). Data on hospital turnover rates in the U.S. will also be presented for reference. In addition, the changes in the operational status of Bethlehem Garden Hospital from the implementation of the BSC to 2023 will be described. This will allow us to evaluate the Bethlehem Garden Hospital case study properly results in terms of lower turnover rates. If BSC can be shown to be effective in reducing turnover, its usefulness in healthcare institutions will increase.

2 Research methods

This paper is similar to the case study by Huang et al. (12), where data triangulation (interviews, action research, and document analysis) was conducted. This study employs an abductive research approach to analyze how BSC functions as a communication tool in healthcare settings. Our research design utilizes a single case study method to enable in-depth exploration and theory development.

2.1 Semi-structured interviews

Phase 1: Initial face-to-face interview (May 18, 2018, 3:00–5:20 pm) with the Administrative Director to gather baseline information about BSC implementation and strategy. Phase 2: Follow-up email interviews from 2022 onwards to collect updated information (adapted due to COVID-19 restrictions).

2.2 Action research

Period: 2018–2024. Focus: Enhancement of BSC and its dissemination among hospital staff. Key activities: Three training sessions (June–July 2019), development of departmental BSC, integration of SDGs into BSC framework.

2.3 Document analysis

External materials to capture communication outside the organization (2016–2024): website content, blog posts, PR magazines, third-party evaluation reports, and papers by hospital personnel.

Our analysis followed an abductive approach, which involved iterating between existing theories and empirical findings while maintaining openness to new theoretical insights. "Abduction refers to a creative inferential process aimed at producing new hypotheses and theories based on surprising research evidence" (26).

We employed multiple validation strategies to ensure research quality and trustworthiness, including data triangulation, multiple researcher verification, and regular stakeholder discussions throughout our longitudinal observation period from 2016 to 2024.

3 Bethlehem Garden Hospital case study overview

Bethlehem Garden Hospital, located in Kiyose City, Tokyo, Japan, provides an intriguing case study for examining the potential impact of the BSC on employee turnover rates in healthcare institutions. This long-term care hospital, with a capacity of 96 beds, has a rich history dating back to its founding in October 1933 as a sanatorium farm. It obtained its hospital license in April 1935 and initially specialized in tuberculosis treatment. As of January 1, 2021, the hospital employed 199 staff members, comprising 90 full-time and 109 part-time employees.

The hospital operates under the ownership of the social welfare corporation Jiseikai, which manages various educational and social service institutions. Bethlehem Garden Hospital adheres to a Christian Catholic philosophy, encapsulated in its mission statement: "We inherit the will of Father Joseph Flaujac, our founder, and faithfully provide warm medical care for the sick according to the spirit of Christ's love." This mission is supported by seven fundamental policies emphasizing patient dignity, safety, communication, continuous training, teamwork, cooperation with other facilities, and sound management.

The evolution of BSC at Bethlehem Garden Hospital can be traced through five distinct periods.

3.1 Initial implementation (2016)

The hospital initiated BSC implementation following the appointment of Makoto Kikuchi as the new Administrative Director. While this marked an important strategic shift, the initial implementation faced challenges due to a lack of external guidance and clear strategy. This period highlighted the importance of proper preparation and strategic clarity before implementation.

3.2 Early operation (2017–2018)

The first BSC operation revealed several critical areas requiring improvement, including misalignment of the four perspectives, particularly in the causal link between patient and financial perspectives, insufficient objective alignment across departments, and lack of coherence among strategic themes, objectives, and indicators. Despite these challenges, the hospital demonstrated its commitment to transparency by publicly disclosing its BSC on its website. The BSC challenges identified at this period are detailed in Ito (27).

3.3 Enhancement period (2018–2020)

External expert engagement led to significant improvements through structured training programs, comprehensive strategy map development, and departmental BSC implementation. The hospital used a SWOT analysis to understand the current situation and then created a BSC and began rolling out departmental BSC across seven departments. These improvements corresponded with decreased turnover rates and increased employee engagement scores. Huang et al. (12) describe the training program in detail.

3.4 Integration period (2020–2022)

The BSC evolved to address broader organizational responsibilities by integrating SDGs and introducing new indicators for ICT implementation, environmental impact, and social responsibility. The hospital enhanced stakeholder communication through multiple channels (e.g., websites, blogs, PR magazines, conference activities, community interaction activities, questionnaire surveys), demonstrating how BSC can adapt to changing organizational needs while maintaining strategic focus. A discussion of the integration of the BSC and SDGs is detailed in Nemoto (28).

3.5 Maturation period (2022–2024)

The BSC reached a more sophisticated stage with explicit linkages to SDGs targets (link SDGs targets with BSC's action plans), enhanced risk management indicators, and metrics for employee motivation. This period has resulted in a further decline in turnover rates, although future trends must be monitored.

This evolution demonstrates how BSC can transform from a basic performance measurement tool into an integrated tool for strategic management and communication. The hospital's experience suggests that successful BSC implementation requires phased deployment, external expertise, continuous refinement, and strong stakeholder engagement, ultimately leading to significant organizational improvements.

One of the most significant outcomes observed following the implementation and refinement of the BSC was a substantial decrease in employee turnover rates. The data provided by the hospital shows a marked decline in turnover rates from 23.6% in 2015 (pre-BSC implementation) to 3.4% in 2023. This reduction is particularly noteworthy when compared to industry averages in Japan and internationally. Turnover rates are discussed in the next section.

The Administrative Director of Bethlehem Garden Hospital provided insights into the relationship between BSC implementation and the reduction in turnover rates. Kikuchi (40) noted that before BSC adoption, the hospital faced challenges with high turnover, particularly in the nursing department, which experienced rates in the 30% range. The recruitment landscape was difficult, often requiring reliance on recruitment agencies. New hires frequently struggled to acclimate to the organizational atmosphere, leading to swift departures and perpetuating a negative cycle of acceptance, disillusionment, and exhaustion.

The Administrative Director emphasized that the BSC served as an effective tool for visualizing and disseminating the organization's values to all staff members. He stated, "The most valuable asset that can be attained from efforts to make values visible is 'trust between the organization and staff.' I believe this 'relationship of trust' has contributed considerably to the reduction in turnover."

While a direct causal relationship between BSC implementation and reduced turnover rates cannot be definitively established, the case of Bethlehem Garden Hospital suggests a potential relationship. The BSC appears to have facilitated better communication of the hospital's mission, vision, and strategy, promoted alignment between individual and organizational goals, and fostered a sense of trust and engagement among employees.

4 Discussion

In Japan, the MHLW has surveyed the turnover of the healthcare and welfare industry, and the JNA has surveyed nursing staff turnover. Data on hospital turnover in the United States will also be presented for reference (Table 1). These data present turnover rates from 2015 to 2023, the same period as the data from Bethlehem Garden Hospital. However, the JNA survey does not have data for 2015 and 2016. Thus, the 2014 data is included for reference. The JNA has not yet released data for 2023.

Table 1 shows that the healthcare and welfare industry turnover rate is around 14%, while the nursing staff turnover rate is around 11%. Therefore, Bethlehem Garden Hospital had a higher-than-average turnover rate until 2018 (If nursing staff turnover is to be used as a comparison, 2019). However, since then, it has had a lower-than-average turnover rate. Compared to the turnover rate of the United States hospitals, Bethlehem Garden Hospital's turnover rate in 2015 was 23.6%, much higher than the United States turnover rate (17.1%). However, after 2016, when Bethlehem Garden Hospital implemented the BSC, the turnover rate was lower than that of the United States.

In summary, Bethlehem Garden Hospital's turnover rate has changed from being higher than the average turnover rate in Japan and the United States to being lower since the introduction of BSC. As noted earlier, turnover in healthcare is an important indicator related to quality of care and patient safety. This could be a piece of evidence that the BSC has an impact on the quality of care and patient safety.

The Administrative Director cites employee motivation as a factor associated with lower turnover. In other words, he points to a relationship with employee engagement. Bethlehem Garden Hospital has been conducting an employee survey (excluding those in positions of chief or higher) since 2015. This survey asked questions related to employee engagement. Table 2 presents figures

TABLE 1 Comparison of turnover rates.

Years	Bethlehem Garden Hospital	Healthcare and welfare industry	Full-time nursing staff	Hospital average in the United States
2015	23.6%	14.6%	None (2014: 10.8%)	17.1%
2016 (BSC implementation)	15.4%	14.9%	None	16.2%
2017	15.6%	14.5%	10.9%	18.2%
2018	13.1%	15.5%	10.7%	19.1%
2019	12.0%	14.4%	11.5%	17.8%
2020	8.7%	14.2%	10.6%	19.5%
2021	7.8%	13.5%	11.6%	25.9%
2022	9.0%	15.3%	11.8%	22.7%
2023	3.4%	14.6%	None	20.7%

Source: Prepared by authors based on materials provided by Bethlehem Garden Hospital; (40–44).

TABLE 2 Comparison of turnover rates and employee engagement scores in the Bethlehem Garden Hospital.

Years	Turnover rates	Employee engagement scores
2015	23.6%	72.1%
2016 (BSC implementation)	15.4%	74.2%
2017	15.6%	74.1%
2018 (Action research begins)	13.1%	None
2019 (Training programs and departmental rollout begins)	12.0%	84.1%
2020	8.7%	89.8%
2021	7.8%	89.9%
2022	9.0%	86.3%
2023	3.4%	87.9%

Source: Prepared by authors based on materials provided by Bethlehem Garden Hospital; Kikuchi (40).

on turnover rates and employee engagement. These figures are based on the questions "Do you feel motivated and happy at work?" (2015–2017) and "Do you take pride in your work?" (2019–2023), based on the percentage of positive responses to these questions. Note that the 2018 numbers are "None" because the survey was not administered in 2018.

As shown in Table 2, employee engagement scores improved at Bethlehem Garden Hospital, along with a decrease in turnover. This is similar to previous studies [e.g., (29–34)] showing that employee engagement leads to lower turnover. Some of these studies point to the impact of communication on employee engagement. In other words, they suggest that using the BSC as a communication tool can encourage employee communication, which can lead to increased engagement. Higher employee engagement scores may improve the quality of care (35).

The trend of high engagement scores needs to be interpreted as a ceiling effect. The ceiling effect refers to the phenomenon in which measurements are concentrated near the upper end of the scale (36). Gallup, Inc. (37) shows that even best-practice organizations typically maintain engagement scores around 70–73%, with their highest recorded score being 73% in 2020. In light of this, the hospital's scores of 86–90% are remarkably high, and the subsequent stability at this level suggests that employee evaluations of the organization have crossed a certain threshold and have reached a stable state. This is particularly notable given that Japanese people generally tend to have low engagement scores (38). Although not an ongoing survey, Gu & Itoh (39) noted through a 2013 survey that 83% of Japanese physicians, 61% of pharmacists and technicians, and 31% of nurses were satisfied with their jobs. While exact comparisons are difficult to make due to differences in measurement methods and timing, these benchmarks suggest that the engagement scores of the Bethlehem Garden Hospital are exceptionally high in the Japanese healthcare context.

Also noteworthy is the change from 2019 to 2020: as described by Huang et al. (12), Bethlehem Garden Hospital introduced a training program with external BSC experts as part of its communication management starting in 2019. Since 2019, when the new communication program was introduced, there has been an accelerated improvement. The turnover rate decreased from 12.0% in 2019 to 8.7% in 2020 and further to 7.8% in 2021. Similarly, engagement scores also showed marked improvement: after hovering around 74% from 2015 to 2017, scores rose to 84.1% in 2019 and continued to improve, reaching 89.8% in 2020 and 89.9% in 2021. The latest data available for 2023 shows a turnover rate of 3.4% and an engagement score of 87.9%. This could be strong evidence supporting the usefulness of communication management using the BSC. However, the departmental rollout of the BSC under the guidance of an external expert has also taken place in conjunction with the introduction of the training program. Therefore, the possibility of an interaction effect on turnover and engagement should be considered.

These discussions indicate that the Bethlehem Garden Hospital case study demonstrates the importance of communication in healthcare institutions and the usefulness of the BSC as a communication tool.

5 Conclusion

This study examined the role of the BSC as a communication tool in addressing employee turnover at Bethlehem Garden Hospital in Japan. The findings suggest that the implementation and improvement of the BSC coincided with a significant decrease in turnover rates, from 23.6% in 2015 to 3.4% in 2023.

This reduction is particularly noteworthy when compared to the average turnover rate in the Japanese healthcare and social services industry (approximately 14%) and the turnover rate of nursing staff (approximately 11%). The case study highlights several key points:

1 The BSC, when properly implemented and communicated, can serve as an effective tool for aligning organizational goals and fostering employee engagement.
2 The reduction in turnover at Bethlehem Garden Hospital corresponded with an increase in employee motivation and engagement scores, supporting previous research on the relationship between engagement and retention.
3 The use of the BSC as a communication tool can contribute to improved organizational trust and employee understanding of the institution's mission, vision, values, and strategy.

By fostering improved communication, alignment of goals, and employee engagement, the BSC may offer a promising approach to improving workforce stability and, ultimately, the quality of care.

While these findings are promising, it is important to note the limitations of this study. As a single case study, the results may not be generalizable to all healthcare settings. In addition, while the potential relationships between BSC implementation and reduced turnover are strong, causality cannot be definitively established without further studies. It should also be noted that the study is based on the Japanese context. Different organizational contexts, cultures, and resource availability could affect BSC implementation and outcomes. Furthermore, data collection was partially constrained by COVID-19 restrictions, necessitating adaptation of research methods, particularly in the later stages of the study.

Future research directions may include comparative studies across multiple healthcare institutions to validate the impact of BSC on turnover rates; longitudinal studies to assess the long-term effects of BSC implementation on employee retention and engagement; qualitative research to explore the specific mechanisms by which the BSC influences employee perceptions and behaviors; exploration of potential cultural or organizational factors that may affect the effectiveness of the BSC in different healthcare settings.

Despite these limitations, this study makes several important contributions. Theoretically, it extends our understanding of how strategic management tools can enhance communication in the organization. Practically, it provides insights into the effective implementation of BSC in healthcare settings, particularly for addressing critical issues such as employee turnover and engagement. The study also demonstrates the potential of integrating global sustainability goals into local organizational practices through BSC implementation.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

FG: Supervision, Writing – review & editing. YH: Supervision, Writing – review & editing. MN: Funding acquisition, Methodology, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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A cost-reducing reimbursement programme? Effects of value-based reimbursement on healthcare costs

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Value-based reimbursement programmes have become increasingly common in attempts to bend the cost curve of healthcare without negative effects on quality. The aim of this study was to analyse the effect of introducing a value-based reimbursement programme on the cost to third-party payer. We performed a retrospective observational study with a before and after design based on the introduction of a value-based reimbursement programme in Sweden. We analysed patient level cost data from inpatient and outpatient care of patients undergoing lumbar spine surgery, 2006–2015. The average 1-year episode cost decreased 11 percent during the first 2 years with the value-based reimbursement. The number of patients increased 22 percent during the same period, causing the total cost to increase by 8 percent. The value to third-party payer increased after the introduction of the value-based reimbursement since more patients were treated and attained a positive outcome. The decreased episode cost may be a result of better coordinated post-discharge care. Another explanation could be that costs previously borne by the third-party payer are shifted onto the healthcare providers. Thus, it is crucial that providers find a sustainable way of delivering care in the long term to retain value. Interlinking patient records facilitates a holistic perspective among healthcare providers raising awareness of health care utilization through the whole care chain.

KEYWORDS

value-based, reimbursement, bundled payment, pay-for-performance, PROM (patient reported outcome measures), cost, healthcare cost and resource utilization, EQ-5D

1 Introduction

To promote quality in healthcare and at the same time bend the cost curve, reimbursement has shifted from fee-for-service to alternative payment models, such as value-based reimbursement. Value-based reimbursement programmes (VBRP) strives to synchronize financial incentives with professional values, often by integrating multiple payment models, e.g., bundled payment and pay-for-performance (P4P) (1). Other commonly used terms for VBRP include value-based payment models (2) and value-based purchasing models (3). Ideally, a VBRP promotes both quality improvement and cost control to deliver value defined as "the health outcomes achieved that matter to patients relative to the cost of achieving those outcomes" (4). Consequently, value is conceptualized as the ratio between outcome and cost

(5). In theory, a VBRP contains both quality enhancing and cost-containing incentives to generate value (4, 6).

In this study, we analyse how the cost to third-party payer (Region Stockholm) is affected by the introduction of a VBRP within elective spine surgery in Region Stockholm, Sweden. Low back pain affects an estimated 80–85 percent of the global population at some point in their life (7), resulting in a significant and growing economic burden (8) where indirect costs has been estimated to account for 66–84 percent of the total cost (9, 10). Thus, an effective reimbursement programme that considers the full care chain is essential. A VBRP with incentives for a holistic approach may be particularly suited for spine surgery, given the variability in clinical guidelines and the incomplete evidence regarding who benefits from surgical intervention (11). The Stockholm VBRP (STHLM-VBRP) has a unique design because it extends the financial responsibility of healthcare providers to include all healthcare utilization related to spine surgery for 1 year following the index surgery, including treatment of complications and physiotherapy. As a result, providers face a more extensive financial responsibility than those in other assessed programmes (12, 13). Further, the performance measure used in the STHLM-VBRP is based on the level of pain the patient reports 1 year after surgery.

Systematic literature reviews on VBRP (1, 3, 14–16) provides mixed evidence on the effect on cost, as well as reviews on the specific features included in the STHLM-VBRP such as P4P (17–20), and bundled payment (21–23). Later systematic reviews of VBRP however have shown promising results in terms of lower spending growth with equal or improved quality (15). One study has so far shown that the STHLM-VBRP had no negative effect on quality (24). However, to assess whether the STHLM-VBRP increased value or not, the cost-implications needs to be investigated.

The overall aim of this study is to analyse the association between costs to third-party payer (Region Stockholm) and the introduction of a value-based reimbursement programme (STHLM-VBRP).

2 Materials and methods

2.1 Healthcare setting

Sweden has universal health coverage and the healthcare system is publicly financed. There are 21 self-governing regions in Sweden with the responsibility to provide and finance healthcare through tax-revenues. Region Stockholm accounts for 26 percent of the inpatient care in Sweden (25) and is thereby the largest region.

For a private healthcare provider to deliver care, they must establish a commissioning contract with the relevant region. A commissioning contract is established either through the Public Procurement Act (26) or through the Act on Systems of Choice (27). Within the healthcare context, the Act on Systems of Choice is more commonly known as Patient Choice, which is the term we will use hereafter. Under the Public Procurement Act, each healthcare provider specifies the price at which they can perform a certain number of surgeries. If the Region accept this price, the provider is authorized to carry out the agreed-upon number of surgeries for the contracted period. Within the framework of Patient Choice, the Region sets the price level that healthcare providers can opt to accept, without any restriction on volume. The idea of Patient Choice is that the preferences of patients should drive competition. This approach emphasizes competition based on quality rather than price, which is essential for value-based healthcare (28).

In 2013, Region Stockholm switched from contracting healthcare providers through the Public Procurement Act to Patient Choice in elective spine surgery (i.e., surgeries that are scheduled in advance and does not involve any emergency). It was further decided that a value-based reimbursement programme (VBRP) should be introduced simultaneously. Both public and private healthcare providers perform elective spine surgery in Region Stockholm. However, Patient Choice and the VBRP only include the private healthcare providers. There were three accredited private healthcare providers at the time of the introduction of Patient Choice and they performed most of the surgeries. The STHLM-VBRP encompasses both degenerative lumbar and cervical surgeries; however, not all healthcare providers were accredited for cervical spine surgery. Consequently, this study focuses on degenerative lumbar surgery. The categories are defined by specific diagnoses and surgical procedures (see Supplementary Table S1) and have been employed for an extended period in the national quality registry for spine surgery (SweSpine) (29).

2.2 The value-based reimbursement programme

An extensive description of the Stockholm VBRP (STHLM-VBRP) can be found in previous published studies (24, 30, 31) but the main features are summarised below.

The healthcare provider receives a prospective payment when the surgical procedure is registered. This payment comprises a bundled payment and an expected performance-based payment (Figure 1). The bundled payment should cover the costs of the spine surgery but also care related to the surgery during the following year. Hence, the healthcare provider receives no further payment to treat complications, reoperations and rehabilitation visits related to the surgery. When surgically treated patients seek care elsewhere, the healthcare provider that received the bundled payment will be billed. Thus, to stimulate an effective and integrated care chain, the cost responsibility is extended to include healthcare that is supplied by other healthcare providers. The complication and rehabilitation activities depicted in Figure 1 are just examples of activities that were previously reimbursed separately.

To promote needs-based healthcare, it is essential to minimize financial risk disparities among patients. The STHLM-VBRP limits the financial risk between patients by adjusting the prospective payment for age, gender, and comorbidity level. Further, surgical procedures that involve surgery on more than two levels of the spine generate an additional payment to the provider.

The performance-based payment is used as a complement to the bundled payment to promote a focus on quality but also to prevent healthcare provider from skimping on necessary care. The performance-based payment used in STHLM-VBRP is based on the outcome measure Global Assessment (GA), which involves a retrospective transition question asked 1 year after surgery ("How is your back/leg pain today compared to before the surgery?"). The performance-based payment is based on leg pain for patients with disc herniation or spinal stenosis, and back pain for patients with segmental dysfunction and spondylolisthesis. The patient can choose between six response options (pain free, much better, somewhat

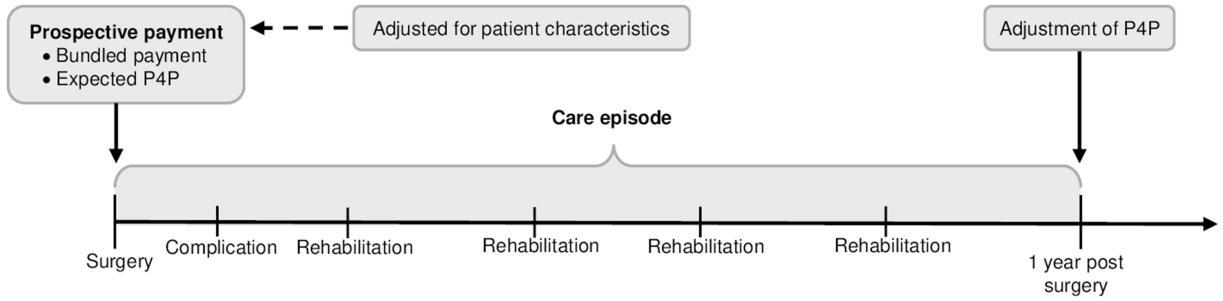


FIGURE 1
Illustration of the value-based reimbursement programme used in elective spine surgery in Region Stockholm (STHLM-VBRP), Sweden. Modified illustration from Eriksson et al. (24).

better, unchanged, worse, did not have pain before the surgery) (32). The registration of GA is administered and managed by SweSpine (33). Importantly, healthcare providers are not in any way involved in this process.

The expected P4P, which is included in the prospective payment to healthcare providers, is based on national historic outcomes of GA registered in SweSpine. One year after surgery, the expected P4P is adjusted according to the actual patient reported outcome of GA. Patients with better results than predicted generated a positive adjustment in the range of 1 to 6 percent of the prospective payment (24). Whereas patients with worse results than predicted generated a negative adjustment in the range of −1 to −18 percent of the prospective payment (24). Thus, there are stronger financial incentives associated with avoiding negative outcomes compared with reaching positive outcomes.

2.3 Study population

The study population consisted of patients ≥18 years of age, living in Region Stockholm and undergoing lumbar spine surgery 2006–2015. Patients were included based on diagnosis (ICD-10) and surgical procedure code (NCSP). The new reimbursement programme only includes private healthcare providers. Hence, only patients who were surgically treated by a private healthcare provider were included in the analysis.

2.4 Study design and data sources

This was a retrospective observational register study, using a before and after design. The value-based reimbursement programme was introduced in October 2013; hence the study period contains 7.75 years before the introduction and 2.25 years after the introduction. Data were collected until the end of 2016 to account for the reimbursement adjustment 1 year after surgery for patients surgically treated in 2015.

Patient level data on diagnosis, surgical procedure, age, gender, costs, were extracted from the Stockholm regional patient registry (VAL). When a patient was identified with the right combination of diagnosis and surgical procedure code for spine surgery, all healthcare utilization was extracted for the following year. Socioeconomic data on income, educational level, employment, and country of birth were extracted from Statistics Sweden. Patient reported outcome measures were extracted from Swespine.

The National Board of Health and Welfare anonymised and interlinked data from VAL, Swespine and Statistics Sweden. Data were obtained with ethical approval.

2.5 Study variables

The primary outcome was total and mean episode cost for patients undergoing lumbar spine surgery, from the perspective of a third-party payer, which in our case was Region Stockholm. The costs included were all healthcare costs during the 1-year episode after lumbar spine surgery, which includes inpatient care, outpatient care, primary care, and rehabilitation.

To compare the populations undergoing surgery before and after the introduction of the STHLM-VBRP we controlled for patient baseline characteristics by including variables on age, gender, body mass index (BMI), comorbidity level measured with Charlson comorbidity index (34), EQ-5D-3L, Oswestry Disability Index (ODI), annual income, educational level, employment status, and whether the patient was born outside of Europe. EQ-5D-3L comprises five dimensions (mobility, self-care, usual activities, pain/discomfort and anxiety/depression), with three levels (no problems, some problems, and extreme problems) (35). In Swespine the EQ-5D-3L has been converted into a single summary index using the tariff by Dolan (36). The ODI is a recommended condition-specific outcome measures for spinal disorders (37, 38) and comprises ten items: pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sex life, social life, and traveling. Based on these items, patients get a percentage score of disability, where 0 percent corresponds to no disability and 100 percent corresponds to full disability.

2.6 Analysis

Patient characteristics are described using proportions for categorical data and mean and standard deviation for continuous data, differences between populations was tested using student's *t*-test and Wilcoxon rank sum test for categorical variables. Analysis of patient

characteristics of the same patient population has previously been published in Eriksson et al. (24).

To assess the effect of the STHLM-VBRP on cost to the third-party payer (Region Stockholm), we analysed the total episode cost per year and the mean episode cost of patients surgically treated from 2006 until the end of 2015. The STHLM-VBRP contract holds healthcare providers financially responsible for related services (complication treatment and physiotherapy) for 1 year following surgery. In our data however, we are not able to distinguish related healthcare from unrelated. Therefore, we include all healthcare utilization in the year following surgery, assuming that unrelated healthcare remains consistent before and after the introduction of STHLM-VBRP. Thus, the episode cost encompasses not only the cost of spine surgery but also all healthcare utilization – including primary, outpatient and inpatient care – during the year following the index surgery.

As a first step, costs are presented comparing the two last years prior to the introduction of the STHLM-VBRP with the two first years following the introduction. The second step takes a longer time-perspective into account to compare trend and level 2006–2015. We used segmented regression analysis (39) to assess potential changes in level and trend of costs over time, from 2006 until the end of 2015. The time series (2006–2015) is interrupted by the introduction of STHLM-VBRP in 2013, creating two segments of interest. This allows us to identify changes in trend and level of costs after the introduction. The independent variables used were: *Time*, indicating the number of months after January 2006; *VBRP*, indicating the introduction of the STHLM-VBRP in 2013; *Time after*, indicating the number of months after the introduction of the STHLM-VBRP; *July*, indicating the month of July since fewer patients undergo surgery during this month due to summer holidays. A sensitivity analysis was conducted based on a shorter period (2011–2015) but with equal amount of data points pre- and post-intervention.

Patients with missing values in reimbursement were excluded from the analysis. Statistical significance was assessed at the 5 percent level. Analyses were performed using SAS 9.4. All costs were adjusted to the 2016 price level and presented in EUR with an exchange rate corresponding to 1 SEK = 0.11 EUR.

3 Results

From year 2006 until the end of 2015 were 10,389 patients surgically treated for lower back pain; 6,738 patients were treated before the introduction of the VBRP and 3,651 after the introduction. There were no significant differences between patients surgically treated after the introduction compared to before the introduction of STHLM-VBRP regarding age, gender, BMI, EQ-5D level prior to surgery and educational level. The comorbidity level of patients treated after the introduction (M = 0.31, SD = 0.78) was higher ($p < 0.01$) compared to the comorbidity level of patients treated before the introduction (M = 0.24, SD = 0.71), indicating a slightly sicker patient group after the introduction. However, the ODI-level indicated a less impaired population ($p = 0.16$) after the introduction (M = 41.16, SD = 16.41) compared to before the introduction (M = 41.88, SD = 15.87). Patients treated after the introduction had a higher ($p < 0.01$) annual income (M = € 31,185, SD = € 44) compared to patients treated before the introduction (M = € 27,449, SD = 26,053). Further, the employment rate among patients treated after the introduction (M = 54.73, SD = 49.78) was higher ($p = 0.94$) compared to patients treated before the introduction (M = 52.67, SD = 49.93). An increased annual income and a higher employment rate indicate higher socioeconomic status among patients surgically treated after the introduction of the VBRP. However, the proportion of patients born outside of Europe was higher ($p < 0.01$) after the introduction (M = 12.01, SD = 29.34) compared to before the introduction (M = 8.22, SD = 22.47).

The number of patients surgically treated by private healthcare providers increased during the study period. The total annual episode cost did also increase with the exception of 2013 and 2015. Figure 2 depicts the development for the total annual episode cost and number of surgically treated patients each year for the period 2006–2015. Comparing the last 2 years before the introduction of the STHLM-VBRP (2011–2012) with the two first years after the introduction (2014–2015), the number of surgically treated patients increased by 22 percent, from 2,641 to 3,215 patients. The total aggregated episode cost of surgically treated patients during the first 2 years with the VBRP, i.e., 2014–2015, amounted to € 27.7 million, which is an 8 percent increase compared with the two last years before the introduction, i.e., 2011–2012. The mean episode cost per surgically treated patient was 11 percent lower during the two first years after the introduction of the VBRP (2014–2015) compared with the two last years before the introduction (2011–2012), € 8,620 compared to € 9,682, respectively.

The result of the segmented regression analysis when considering a longer time frame (i.e., 2006–2015) is presented in Table 1. The total episode cost for all patients surgically treated in January 2006 was estimated at € 236,862. In total, the cost for all surgically treated patients in 2006 reached € 5.7 million. The *Time* parameter in Table 1A represents the trend prior to the introduction of the VBRP, indicating that the total episode cost increased by €10,051 ($p < 0.0001$) each month from January 2006. However, following the introduction of the VBRP, the trend shifted to negative (represented by the parameter *Time* after), counteracting the previous positive trend (see Figure 3A). Consequently, the total episode cost decreased by € 8,684 ($p = 0.0103$, € 10,051 – € 18,735) each month after the introduction of the VBRP. The total episode cost of patients surgically treated in 2015 amounted to € 13.1 million. Following the introduction of the VBRP, the total episode cost level increased with €204,010, however not statistically significant ($p = 0.1146$).

Table 1B presents the estimates for level and trend of the mean episode cost of a surgically treated patient between 2006 and 2015. The mean episode cost of a patient surgically treated in January 2006 was estimated at € 7,104 (<0.0001). Each month, the annual cost per patient increased by € 29 ($p = 0.0003$). The introduction of the VBRP reduced the level of the mean cost per patient by € 360 ($p = 0.6763$) and the trend by € 47 per month ($p = 0.1185$, € 29 before VBRP – € 76 after VBRP), however these changes are not statistically significant. The observations and estimated mean episode cost per patient is depicted in Figure 3B.

A sensitivity analysis conducted over a shorter period (2011–2015), using 27 data points both before and after the intervention, reveals a similar negative trend in costs, although it is not statistically significant (see Supplementary Table S2; Supplementary Figure S1).

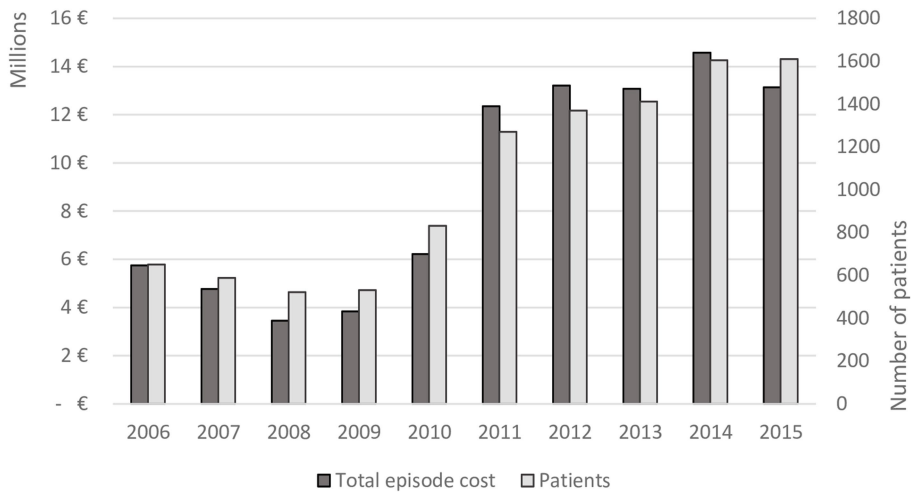


FIGURE 2
The total episode cost and number of surgically treated patients for the time period 2006–2015 in Region Stockholm.

TABLE 1 Parameter estimates predicting the total and mean episode cost of surgically treated patients, 2006–2015.

Parameter	(A) Total episode cost per month (€)			(B) Mean episode cost (€)		
	Estimate	SE	*p*-value	Estimate	SE	*p*-value
Intercept (Jan 2006)	236,862	60,758	0.0002	7,104	408	<0.0001
Time	10,051	1,146	<0.0001	29	8	0.0003
VBRP (Oct 2013)	204,010	128,300	0.1146	−360	861	0.6763
Time after	−18,735	7,178	0.0103	−76	48	0.1185
July	−820,354	105,189	<0.0001	−808	706	0.2547

SE, standard error; Intercept, cost level in January 2006; Time, number of months from January 2006; VBRP, indicates the introduction of the STHLM-VBRP at the end of 2013, which is 92 months after January 2006 (Time = 92); Time after, number of months after the introduction of VBRP (hence Time-91); July, indicates the month of July.

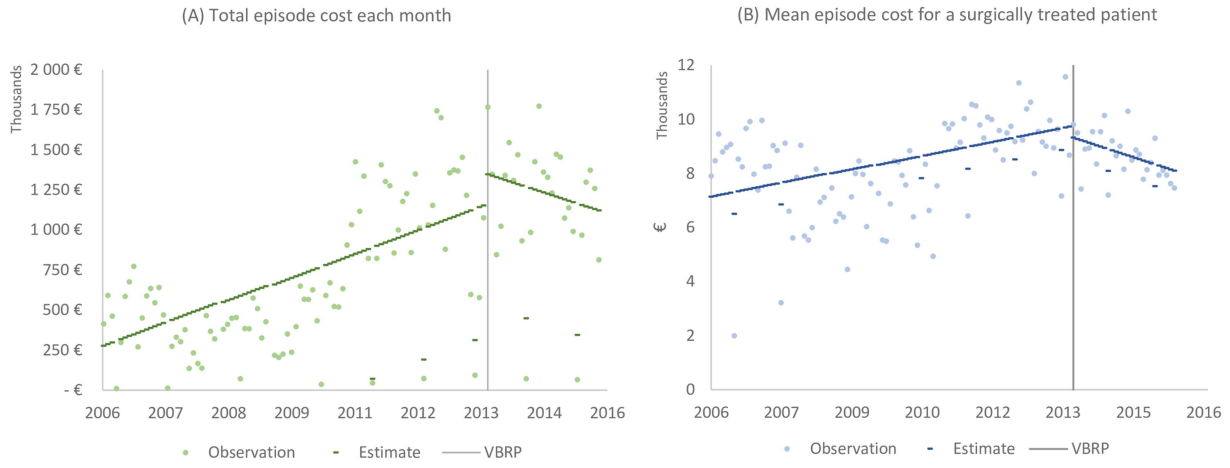


FIGURE 3
The total (A) and mean (B) episode cost for surgically treated patients. The vertical line indicates the introduction of the STHLM-VBRP at the end of 2013.

4 Discussion

In this study we analysed the effect of the STHLM-VBRP on cost to a third-party payer (Region Stockholm). Our results show that the mean episode cost for surgically treated patients decreased by 11 percent following the introduction of STHLM-VBRP. However, due to a 22 percent increase in the number of surgically treated patients, the total episode cost for spine surgery increased by 8 percent. Thus,

the introduction of STHLM-VBRP is associated with decreasing costs while, as reported by Eriksson et al. (24), maintaining patient reported outcome measures (PROM) and thereby enhancing value as defined by Porter (4).

The lower mean cost may result from better coordinated care due to the increased financial responsibility of healthcare providers for post-discharge care, helping to avoiding unnecessary treatments. However, this reduced cost to Region Stockholm could come at the expense of the private healthcare providers. A fourth healthcare provider received accreditation in 2017 (31), suggesting that the reimbursement level was sufficient to attract new healthcare providers. Nevertheless, one of the original healthcare providers closed its business in 2021 due to competitive pressure and strained economy (40). Understanding how this shift in market structure has impacted costs and PROMs would be valuable for assessing long-term consequences of the STHLM-VBRP. When costs are shifted to private healthcare providers concerns arise about whether patients continue to receive adequate care after surgery. Previous studies on the population covered by the STHLM-VBRP found no evidence for negative effects on PROM following the introduction of the VBRP (24).

Consistent with our findings, a multicentre observational study of patients undergoing lumbar fusion reported a reduction in costs following introduction of bundled payment (41). In contrast, Bronson et al. (42), found no effect on cost after introducing bundled payment in spine surgery, while Jubelt et al. (43) reported an increase in costs. Both studies observed a more complex patient mix after the introduction of the programme. Differences in design and context may further explain the heterogenous results, including a shorter episode duration of 90 days compared to the 365-day episode in STHLM-VBRP, and the fact that bundled payment was not combined with P4P. Our study is based on patients surgically treated by publicly financed private healthcare providers in Sweden, whereas the studies by Bronson et al. (42) and Jubelt et al. (43) were conducted at hospital and university clinics in the U.S., respectively. Our study is so far the only one to assess the effect of a one-year bundled payment episode combined with pay-for-performance (P4P) using PROM.

Overall, our results align with studies demonstrating promising outcomes in terms of reduced spending growth and sustained quality levels (15, 17, 23, 44). While systematic reviews have historically presented mixed evidence regarding Value-Based Reimbursement Programmes (VBRPs) (17, 45, 46), the generalisability of these findings has been limited by variation in the design of reimbursement programmes and the context of their implementation, but also by methods used for assessment (3, 45). In response to these limitations, an increasing number of studies have developed frameworks to identify both facilitating and inhibiting factors for a successful VBRPs (2, 3, 6, 15, 16, 47). A key factor often overlooked in these frameworks, as highlighted in this study, is the significance of time, which is crucial for a thorough assessment of the long-term effects of VBRPs.

In the study by Eriksson et al. it was reported that the P4P within STHLM-VBRP was a "stick" rather than a "carrot" for health care providers (24). This in combination with a financial responsibility for a year makes it crucial that healthcare providers come to an understanding of which patients benefit from a surgery and which patients do not. This is something which is continually debated within spine surgery (30, 31). A previous study indicates that socioeconomic factors (education, income, unemployment and country of birth) also affect the outcome of spine surgery (48). In other studies (42, 43), authors argued that the existing DRG system is not well-suited to manage the increasing case complexity and heterogeneity present in modern spinal surgery. It has further been argued that value-based reimbursement in collectively-financed healthcare requires monitoring of socioeconomic patient data in order to maintain equality in service provision (49). Hence, it would probably be beneficial to include risk adjustment of reimbursement based on both clinical and socioeconomic variables to avoid discrimination (48). In the case of the STHLM-VBRP, each payment was individually risk adjusted and the traditional use of DRG was replaced with new categories that were already established in SWESPINE. However, there is no adjustment based on socioeconomic factors. The higher socioeconomic status of patients receiving surgical treatment after the introduction of VBRP may suggest a potential case of cherry-picking. However, the increase in the proportion of patients born outside of Europe after the introduction of VBRP counters this notion, as this demographic factor is considered a risk factor in surgical outcomes in Sweden (48). Another possible explanation for the shift in patient characteristics is the removal of annual limits on the number of patients each healthcare provider could treat. This enables healthcare providers to treat a larger number of patients, potentially leading to a more diverse patient population. Customised reimbursement based on patient-level data may lead to better distribution of healthcare resources towards needs-based healthcare. To reduce incentives for "cherry-picking," a future update of the STHLM-VBRP should include adjustments based on socioeconomic variables.

A limitation of our study is that our dataset does not include patients that were referred to a spine surgeon for assessment but then not surgically treated. Therefor we cannot assess whether cherry-picking or a shift in indications occurred in that part of the care chain. Since the indications for surgery can be rather vague within elective spine surgery there is a risk of "over-treating" patients. This may result in negative side-effects both financially and medically since surgical procedures are more costly and have a greater risk of adverse events. Further, some surgical procedures only show modestly better effect than conservative treatment (11, 50). A concern when providers have no restriction regarding volume is that it might lead to an increased procedural volume of spine surgery without regard to quality, and thus drive cost and diminish the value of spine care (51, 52). To weed out providers that deliver low value care, those who deliver superior outcomes must be rewarded (38). The STHLM-VBRP reward healthcare providers that were able improve the pain of their patients (24), however, when the pain was unchanged or worse healthcare provider had to repay money to Region Stockholm. Thus, the STHLM-VBRP may weed out providers that deliver low value care and increase value to third party payer by decreasing the costs.

Another limitation is due to the observational approach of our study, using a natural experiment design we can only test for association and not causality. Our method introduces various biases; one strategy to minimize confounding and regression to the mean was to extract data over an extended period (i.e., 2006–2015). Using

segmented regression analysis allows us to compare the slopes over time between pre-intervention and post-intervention periods and to assess any outcome discontinuity (change in level) that could occur when the intervention began (58). It further allows us to adjust for seasonal trends, e.g., the month of July was included as a parameter in the regression analysis because of holiday season, during which very few patients undergo surgery, thereby impacting the total cost of spine surgery for that month.

A third limitation is that our data only cover the first 2 years (or 27 moths) with the new reimbursement programme. Our sensitivity analysis indicated that 27 months is insufficient to establish a negative association between VBRP and costs. Previous research by Song et al. (53) has shown that larger improvements in quality do not occur immediately when introducing a VBRP. Thus, it takes time for providers to adapt to the structures of a new reimbursement programme (54) and it is common with transition periods during the implementation (55) that are characterised with "child diseases" and may cause a drop in quality of care (56). Thus, a "wash-out" period would be appropriate to remove potential transition effects. Nevertheless, the transition is an inevitable part of the introduction of a new reimbursement programme and important to consider when assessing the effects since it reflects the first 2 years of using a VBRP.

Lastly, our results reflect the costs from the perspective of a third-party payer, which in our case is Region Stockholm. Consequently, we do not know whether the cost for healthcare providers decreased, therefore we do not know how sustainable this reimbursement programme is. Investigating the profitability of private healthcare providers under the VBRP would be valuable for assessing the true cost of spine surgery. Have the private healthcare providers succeeded in making post-surgery more effective or do they struggle to make ends meet? Do they have a chance to adapt to the new reimbursement level given the load of post-discharge care? Other important aspects affecting the future viability of the STHLM-VBRP is the administrative burden and the micropolitical and professional issues that are in play (57). Only time will provide answers to these questions. As will time show whether these healthcare providers manage to treat these patients efficiently without any negative impact on quality.

5 Conclusion

The cost per patient to third-party payer decreased when a value-based reimbursement programme was used for elective spine surgery. Due to the decreased cost per patient without negative effects on quality or access to care, the STHLM-VBRP seems promising. In order to hold healthcare providers responsible for post-discharge care it is necessary to interlink data from patient registries when using bundled payment. Interlinking patient records facilitates a holistic perspective among healthcare providers raising awareness of healthcare utilization throughout the care chain.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Regional Board of Ethics in Linköping (2015/94-31). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

TE: Data curation, Formal analysis, Methodology, Project administration, Writing – original draft, Writing – review & editing. HT: Conceptualization, Resources, Supervision, Writing – review & editing. A-BW: Data curation, Investigation, Supervision, Writing – review & editing. L-ÅL: Conceptualization, Formal analysis, Funding acquisition, Methodology, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1326067/full#supplementary-material

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Healthcare provider perspectives on barriers and facilitators to integration of cardiovascular disease-related care into HIV care and treatment clinics in urban Tanzania

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Background: The increase in the dual burden of HIV and cardiovascular diseases (CVD), calls for the provision of integrated HIV/CVD care. This study aimed to explore barriers and facilitators to the integration of HIV/CVD care within HIV care and treatment clinics (CTCs) in urban, Tanzania.

Methods: Between March and April 2023, we conducted 12 key informant interviews with healthcare providers at six HIV CTCs in urban, Tanzania. Guided by the Consolidated Framework for Implementation Research (CFIR 1.0), we designed the interview guide and conducted a thematic analysis.

Results: Out of the 11 CFIR constructs explored, three were barriers (cost, availability of resources, and access to information and knowledge), six were facilitators (complexity, relative advantage, patient needs, external policies and incentives, relative priority, and knowledge and belief about the intervention), and two (compatibility and self-efficacy) were both barriers and facilitators. Barriers to integration included a lack of equipment, such as BP machines, lack of space, unavailability of an electronic data-capturing tool at the HIV CTCs for monitoring CVD outcomes, and a shortage of trained healthcare workers, particularly in managing CVD comorbidities according to current recommendations. Providers acknowledged the increasing demand for CVD care among ALHIV and regarded integration as not a complex task. Providers reported that both services could be delivered simultaneously without disrupting client workflow and were determined to offer integrated care within HIV CTCs. Providers expressed concerns about medication costs and recommended that medications should be provided for free as part of the integrated care.

Conclusion: Effective and sustainable HIV/CVD integrated care requires an understating of the existing barriers and facilitators within the HIV CTCs. This study identifies key barriers at HIV CTCs that must be addressed and facilitators to be leveraged before CVD care is integrated into HIV CTCs to ensure that CVD care is delivered effectively within an integrated system.

KEYWORDS

integrated care, cardiovascular diseases, HIV, CFIR, barriers, facilitators, ALHIV, Tanzania

Introduction

Cardiovascular diseases (CVD) remain the leading cause of morbidity and mortality worldwide (1). Adults living with HIV (ALHIV) are more likely to experience CVD compared to individuals without HIV infection (2). The excess CVD risk in this population is a result of a combination of behavioral risk factors (3, 4) and HIV infection-associated chronic inflammation and immune dysregulation (5). ALHIV are also reported to experience severe forms of CVD complications that manifest earlier compared to individuals without HIV infection (5, 6). As life expectancy increases among ALHIV, the burden of CVD among ALHIV is expected to rise significantly, threatening ALHIVs' quality of life and overall survival (7, 8).

About 80% of the global CVD morbidity and mortality is reported in Sub-Saharan Africa (SSA) (9), a region that simultaneously has 70% of the global HIV burden (10). To address this double burden of disease, international health agencies and guidelines advocate for the integration of CVD prevention and care into HIV care and treatment clinics (CTCs), using the resources including providers and infrastructure of well-established HIV care programs (11, 12). Integration of CVD care into some HIV CTCs in SSA has been proven feasible (13, 14) and effective in reducing the overall CVD risk, through improving primarily blood pressure and glycemic control, and increasing patient satisfaction among ALHIV (15–17).

In Tanzania, about 1.7 million people are living with HIV (10). On the other hand, age-standardized total CVD death rate is estimated to be 13%, making it one of the highest in SSA. The percentage of disability-adjusted life years (DALYs) attributed to CVD is 5.1% for men and 4.6% for women (18). HIV infection is associated with a higher incidence of CVD, HIV prevalence among patients with stroke in Tanzania was 20.9% (19). Burden of CVD risk factors is also high among ALHIV in this setting; data suggest that 26.2–53.3% of ALHIV are hypertensive (BP ≥140/90 mm/Hg), 4.2–11.1% are diabetic (RBG > 11.1 mmol/L), 13.3% are obese and 20% have dyslipidemia (19–22).

The Tanzania national guideline for the management of HIV acknowledges the need to prevent CVD among ALHIV. Specific recommendations include patient education on lifestyle modification, screening, and management of the four most common CVD risk factors (hypertension, diabetes, dyslipidemia, and obesity) (23). Despite these recommendations, CVD care provided at the HIV CTCs in Tanzania remains inadequate (24). Our previous study on the experience of ALHIV with hypertension and/or diabetes while accessing care for these comorbidities in Tanzania (24) demonstrated that ALHIV do not receive routine hypertension and diabetes screening and management within HIV CTCs and mostly seek CVD care outside HIV CTCs. The need to attend multiple clinics causes loss of productive hours, increases transport costs, and contributes to treatment discontinuity. Furthermore, ALHIV with hypertension and diabetes do not receive adequate patient education or guidance on the management of these comorbidities (24).

The sustained and coordinated provision of CVD care is critical to ensuring the gains in life expectancy resulting from effective antiretroviral therapy (ART) are not reversed (25). Before CVD care is integrated into HIV CTCs, it is essential to understand barriers and facilitators that may influence the successful implementation and effective provision of integrated care. One study that reported on the barriers and facilitators to providing integrated HIV/CVD care in HIV CTCs in Tanzania, reported limited number of factors and did not use established frameworks (26). In this study, we applied the Consolidated Framework for Implementation Research (CFIR) (27) to formally explore providers' perspectives on the barriers and facilitators to the integration of CVD care within Tanzanian HIV CTCs. CFIR is a robust and broadly used implementation science framework, designed to identify context-relevant barriers and facilitators for adapting interventions across multiple dimensions (27, 28). The use of the implementation science framework (CFIR) allows a formal methodology for selecting implementation strategies (29). Understanding the factors that influence integration is important for designing contextually appropriate HIV/CVD integrated care for ALHIV in Tanzania.

Methods

Study design

We conducted a qualitative study employing a phenomenological approach guided by CFIR to explore the perspectives of providers in HIV CTCs on the barriers and facilitators to the integration of CVD care into HIV CTCs in Dar es Salaam, Tanzania.

WHO defines integrated service delivery as *"The organization and management of health services so that people get the care they need, when they need it, in ways that are user-friendly, to achieve the desired results and provide value for money"* (30). In this study, we defined HIV/CVD integrated care as the provision of CVD care at the HIV CTC, which includes the provision of patient education on healthy lifestyle for CVD prevention, screening services, diagnosis, medication prescription (or referral services) for the three most common CVD risk factors: hypertension, diabetes, and obesity.

The phenomenology approach allowed in-depth exploration of the providers' subjective experiences and perspectives (31, 32). In this study we adhered to the consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups (Supplementary file 1) (33).

Study area and setting

This study was conducted in six high-volume HIV CTCs in Dar es Salaam Tanzania. These clinics were randomly selected from a list of 33 high-volume clinics (serving ≥1,500 clients) in the region and represent the three levels of Tanzania's health care delivery system: Regional Referral Hospital (2), District Hospital (2), and Health Center (2). These HIV CTCs are part of our previous study that assessed cardiovascular health and experiences with care for CVD comorbidities among ALHIV (24, 34).

In Tanzania HIV CTCs, visits are scheduled between monthly and up to every 6 months, depending on how stable a client is on ART. Stable clients are defined as clients who are on ART for at least 6 months with no adverse reactions that require regular monitoring, no current illnesses (opportunistic infections (OIs) and uncontrolled comorbidities), have good adherence to ART and clinic visit appointments, and have no indication of immunological or virological failure (24). Figure 1 summarizes the workflow of clients at the HIV CTC. In addition to HIV-related care that includes ART dispensing, screening for opportunistic infections, HIV viral load monitoring, and ART adherence counseling, the guideline for the management of HIV recommends the provision of CVD care (24).

The guidelines recommend HIV CTCs clients receive patient education promoting a healthy lifestyle, undergo blood pressure and body weight measurements, and be screened for diabetes symptoms (polyuria, polydipsia, and polyphagia) at every visit. Blood glucose screening is required every 6 months while blood lipids screening is required annually (24). The guideline also recommends that providers prescribe medication for hypertension, diabetes, and dyslipidemia at the HIV CTC or refer clients with these CVD-risk factors to NCD clinics available at Regional Referral Hospitals and District Hospitals, and outpatient departments (Health Centers).

Study participants

We purposively recruited 12 HIV CTC providers including one HIV CTC facility in-charge and one nurse supervisor from each of the six selected HIV CTCs. In addition to their administrative roles, all participants actively participated in providing care for clients at the HIV CTC during the study period. The proposed sample size was decided based on the recommendations from the literature (35), the available number of available providers with administrative roles within the HIV CTCs, and the researchers' previous experience with qualitative studies involving providers within HIV CTCs.

Data collection and procedures

We conducted 12 face-to-face key informant interviews (KII) between March and April 2023 using a semi-structured interview guide (Supplementary file 2) designed based on CFIR constructs (1.0) (27). This framework comprises five domains: intervention characteristics, outer setting, inner setting, characteristics of individuals, and implementation processes. We explored the four domains (11 constructs; Table 1), out of the five domains (39 constructs) of CFIR. We excluded the 'implementation process' domain because HIV/CVD integrated care has not yet been formally introduced at the HIV CTCs in Tanzania. The constructs explored were agreed upon through discussions with the study team. The selection was based on their relevance to the providers and the current state of HIV/CVD care integration at Tanzania HIV CTCs. The interview guides were piloted with three providers (one facility in charge and two nurse supervisors) at an HIV CTC within a district hospital that was not part of this study.

In addition to the above, we also collected data on the participant's age, highest education level, and years spent serving as the facility in-charge or nurse supervisor. TO (a female epidemiologist) and one research assistant (a male social scientist), both with experience conducting KIIs, conducted the interviews in Swahili language and took field notes. Interviews lasted 45–60 min and were audio recorded with the participants' consent. The interviews were conducted in a private room within the HIV CTC where privacy and confidentiality were maintained. We monitored for emerging themes and by the eleventh interview, no new information was coming from the field (saturation). Audio recordings of the interviews were transcribed verbatim and translated into English language by the research assistant. TO and FN (a female co-author) reviewed the transcripts and the audio recordings to check for accuracy, consistency, and completeness.

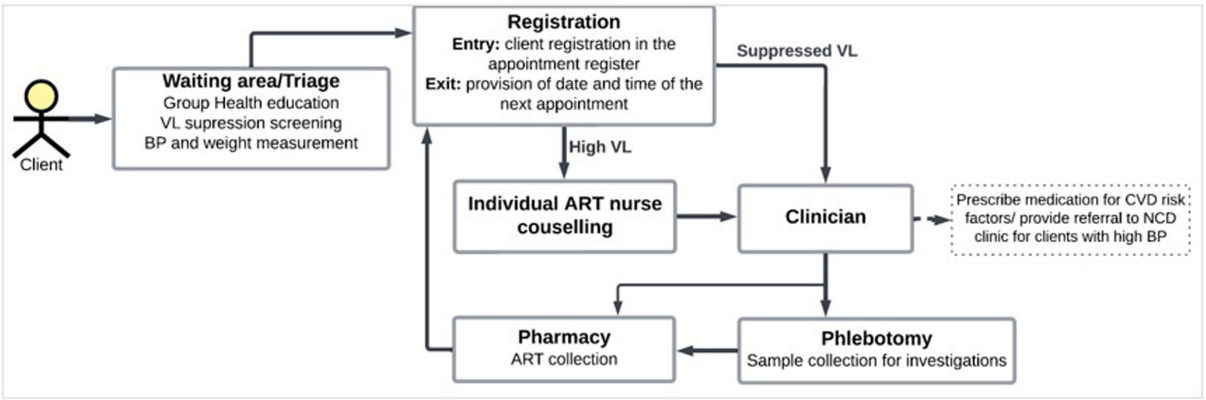


FIGURE 1
Workflow of patients at the HIV CTCs.

TABLE 1 CFIR framework domains and constructs used in the key informant interviews.

Domain	Construct	Definition
Intervention characteristic	Complexity	Perceived difficulty in the provision of CVD care alongside HIV care at the HIV CTC
	Relative advantage	Perceived benefit of integration of CVD care at the HIV CTC
	Cost	Perceived cost related to the provision of CVD care at the HIV CTC (cost of medication)
Outer setting	Patient needs	Extent to which ALHIV's CVD needs are known and prioritized at the HIV CTCs
	External policies and incentives	Extent to which policies and regulations, external mandates, recommendations, and guidelines from the government or implementing partner support/advocate for the integration of CVD care at the HIV CTCs
Inner setting	Compatibility	Perceived alignment between the provision of integrated care and the care currently provided at the HIV CTC (workflow, systems, and processes)
	Relative priority	Perceived importance of integrating CVD care at the HIV CTCs
	Availability of resources	Extent to which resources are available/ allocated to facilitate the provision of CVD care at the HIV CTC including human resources, space, equipment, and electronic data management system
	Access to information and knowledge	Extent to which guidelines and training on the provision of CVD care are routinely available for providers at the HIV CTC
Characteristics of individuals	Knowledge and belief about the intervention	Providers' attitude and values toward integration of CVD care at the HIV CTC including willingness and motivation to provide integrated care
	Self-efficacy	Providers' perceived capability (competence, knowledge, and skills) to provide CVD care including screening, diagnosis, and management of CVD risk factors

CVD, cardiovascular diseases; CVD care, patient education, screening, diagnosis, and management of CVD risk factors.

Data analysis

Data analysis began after the first two interviews and was part of an iterative process. First, TO and FN read the transcripts several times to familiarize themselves with the data. All transcripts were imported into Dedoose software for qualitative data management and analysis. TO and FN then coded the first three transcripts separately and developed the preliminary coding frame. Coding followed the thematic analysis technique (36–38). Deductive codes were drawn from the interview guide, which explored the selected CFIR constructs, while inductive codes were added as they emerged from the data. These codes were compared, and disagreements were resolved through a discussion with the study team until the final codebook was developed. TO coded the rest of the transcripts using the final agreed codebook, however, coding process was thoroughly reviewed by the research team, who are highly experienced in qualitative research. Repeating concepts reflecting the barriers and facilitators to integration of CVD care at HIV CTCs were coded and grouped into CFIR constructs (themes) and domains.

Ethical considerations

The study was approved by the Muhimbili University of Health and Allied Sciences (MUHAS) MUHAS-REC-08-2020-343, National Institute for Medical Research (NIMR)-NIMR/HQ/R8a/VOL.IX/3513 and the Northwestern University (STU00214283) ethics committees. Data collected were de-identified and all participants provided written informed consent to participate including recording and anonymous quotation. Voluntary participation and confidentiality were maintained throughout the study. Participants were encouraged to ask questions at any stage of the research.

Findings

Characteristics of the study participants

Out of the 12 participants, [median age of 46 years (range 38–58)], the majority were females (83%) and had served as facility in-charges or nurse supervisors for >5 years (50%). A summary of the characteristics of study participants is provided in Table 2.

Overview of the key findings

The 11 constructs explored were classified as either barriers, facilitators, or both to the integration of CVD care at HIV CTCs. The CFIR constructs of cost, availability of resources, and access to information and knowledge were classified as barriers. The remaining constructs of complexity, relative advantage, patient needs, external policies and incentives, relative priority, and knowledge and belief about intervention were identified as facilitators, while compatibility and self-efficacy were identified as both barriers and facilitators (Supplementary file 3).

Intervention characteristics

Three constructs under intervention characteristics were explored. These were *complexity, relative advantage, and cost*.

Regarding *complexity*, providers perceive that providing CVD care (patient education, screening, diagnosis, and management of CVD risk factors including hypertension, diabetes, obesity, and dyslipidemia) at the HIV CTC, is not difficult. This is because these providers already conduct some CVD risk factors screening such as BP and weight measurement, during each patient's visit to the clinic. Some facilities have established an NCD integration room within the HIV CTC where a physician from the NCD clinic is available weekly

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TABLE 2 Characteristics of the study participants (n = 12).

Characteristic	Number (n = 12)
Age (median, range) (years)	46 (38–58)
	N (%)
Sex	
Female	10 (83)
Male	2 (17)
Facility type	
Health Center	4 (33)
District Hospital	4 (33)
Regional Referral Hospital	4 (33)
Cadre	
Medical Officer	4 (33)
Assistant Medical Officer	2 (17)
Enrolled nurse	3 (25)
Registered nurse	3 (25)
Level of education	
MD degree	4 (33)
BSc degree	3 (25)
Diploma	5 (42)
Years spent serving administrative role	
<1 year	2 (17)
1–5 years	4 (33)
>5 years	6 (50)

to provide CVD services. In some facilities, BP levels are recorded in the database at the HIV CTC and are being monitored regularly.

> *"I do not think it's difficult because if we can measure a client's blood pressure and body weight and then proceed with other services that (full integration) can also be done"* Participant 3, Regional Referral Hospital.

> *"We have tried to allocate a room we term as an "integration room." It is the room used by a clinician from the NCD clinic to see clients requiring integrated services (related to NCD) during clinic days. Therefore, I do not think it (providing HIV/CVD integrated care) is difficult"* Participant 1, District Hospital.

Related to *relative advantage*, providers reported that integrating CVD care at the HIV CTC would benefit clients in several ways. It would lead to early diagnosis and treatment of CVD risk factors, and allow holistic management and monitoring of patients.

> *"If you tell clients that you are referring them elsewhere, they might go or not go. Sometimes they would say it is difficult to attend two different clinics. Therefore, there are times when they will not attend, others would tell you they have gone to a nearby hospital, hence monitoring becomes challenging"* Participant 2, District Hospital.

In terms of *cost*, providers reported that most patients face financial difficulties, are not covered by health insurance, and hence struggle to afford medication costs. Providers stated that without providing medications for free, integrated care may not yield significant benefits. Diagnosing and prescribing medications without providing them would not fulfill providers' desire to help patients, particularly knowing that many cannot afford them.

> "*Therefore, the main challenge is that most of our clients have low economic status, especially the clients with two or more diseases. So you tell the old man to go buy this medication outside and he says "alright my grandchild but I do not have the money."* Participant 7, District Hospital.

Outer setting

Two constructs under the outer setting were explored. These were *patient needs and external policies and incentives.*

Regarding patient needs, providers admitted that there is a high demand for CVD services among clients within HIV CTCs. Providers also added that CVD care needs are increasingly recognized and are gradually becoming a priority for clients at the HIV CTC.

> *"There was a client with a very high blood pressure and it was clear that there was a need to have the clinic here. Another client asked the doctor; why they do not have the NCD services here (HIV CTC) so that they do not have to go to the other clinic after here (HIV CTC)"* Participant 2, District Hospital.

> "*There was one with kidney issues, hypertension, and DM, attending a clinic at Muhimbili, so he was complaining that his clinics were scheduled on the same day here (HIV CTC) and at Muhimbili, so he came the day before for medications, he wished all services were provided at the same place.* Participant 4, Regional Referral Hospital.

> *"For every adult client, we measure their blood pressure. We did not do this in the past, but since we began this quarter in October we have set up a triage. Before a client receives any service, we must measure their blood pressure.* Participant 1, District Hospital.

While providers report that CVD care, especially screening for hypertension, is increasingly being prioritized, they admitted that HIV care is still the main priority at the HIV CTC. One provider stated that this is because, with the current infrastructure, they are not equipped to monitor CVD risk factors as they do with HIV. Additionally, medications for hypertension are not provided at the HIV CTCs and because they are expensive, providers are never certain whether the patients have procured them after they were prescribed.

> *"Yes, they (hypertension and diabetes) are prioritized but we cannot monitor them the way we monitor ARTs. First, you are not sure if the patient has taken the medications; at most, you have not even dispensed the drug to the patient. You cannot ask the patient why he has not taken medications, (he does not have money)"* Patient 3, Regional Referral Hospital.

With regards to *external policies* providers reported that it is currently mandatory for every patient visiting the HIV CTC to

undergo BP and weight measurement, which must be recorded in the HIV CTC database (CTC2 database). Efforts to implement these recommendations have accelerated with implementing partner support (Management Development for Health – MDH). MDH distributes BP machines, monitors the completeness of BP data in the database, and provides feedback to the HIV CTCs.

> "*Yes, they (MDH) have given us 4 blood pressure machines and 2 weighing scales, the big monitor you see there, also batteries sometimes are provided by the hospitals but sometimes there is a delay from procurement, so they also give us batteries*" Participant 4, Regional Referral Hospital.

> "*Blood pressure and even the blood glucose columns have been added to the new CTC2 card, so we cannot leave the column blank. In the past, there was no follow-up for hypertension and diabetes but now we follow up.* Participant 9, Regional Referral Hospital.

Providers added that the introduction of multi-month dispensing (MMD) of ART (at 3 and 6 months MMD) has significantly reduced the daily patient load at the HIV CTC. This provides an opportunity to introduce CVD care services as an additional service at the HIV CTC.

> *"We give a fixed number of pills let us say 90 so there are some days where the number of clients is very high, but there are days we have few patients like 20 or forty. Currently, the patients are not as many as they used to be in the past"* Participant 12, Regional Referral Hospital.

Another provider warned that patients on the MMD scheme might need to visit the clinic monthly for CVD care, which could cause the clinic to become overcrowded with clients as it was in the past.

> *"A stable client comes for his medications after six months and if you ask him to come monthly for hypertension monitoring, we will have congested clinics as before"* Participant 4, Regional Referral Hospital.

Inner setting

Four constructs under the inner setting were explored. These were *compatibility, relative priority, availability of resources, and access to knowledge and information.*

In terms of *compatibility,* providers reported that the current setup of services at the HIV CTC (Figure 1) allows for the seamless integration of CVD services without disrupting patient workflow. Integration will not be a problem if both services are provided concurrently.

> *"I honestly do not see any problem, unless it was a service that you provide at a separate time. But if I see them at once, they can come with their test results, and I can review the clinical notes to see what s/he received from the beginning. I do not think that will be a problem"* Participant 7, District Hospital.

However, providers added that the electronic data-capturing tool at the HIV CTC (CTC2 database), accommodates only a few non-HIV outcomes such as BP measurements. Data on other CVD risks such as glucose and medications for these conditions are not required to be recorded. The main hospital database which captures all outcomes including medication prescribed, is not installed at the HIV CTC, and the HIV CTC and the main hospital database are not linked. Providers emphasized that linking the two databases would ensure that they can attend to patients with CVD comorbidities at the HIV CTC and record their progress in the main hospital database for more efficient monitoring and documentation.

> "*At our center apart from cost, the main issue is the integration of the systems, meaning that when a client comes in, he should first be registered in the hospital registration system so that he is not required to register again when he needs to be seen by a doctor for CVD services, that will help in everything, all patient could receive services here (HIV CTC)"* Participant 9, Regional Referral Hospital.

Regarding *relative priority,* providers stated that the introduction of CVD services at the HIV CTC is considered important as it will allow the simultaneous provision of highly needed CVD care alongside HIV care. Integration will consequently reduce the time and money patients spend traveling between clinics.

> *"It will save them time, instead of coming here and going elsewhere. If the client comes here to the clinic, the client knows that s/he will receive all services at once. So, it will minimize cumbersome movements"* Participant 1, District Hospital.

Related to the *availability of resources,* providers at lower-level health facilities (District Hospitals and Health Centers) reported a lack of space and human resources to provide CVD care alongside HIV care. However, this was not the case for providers at Regional Referral Hospitals.

> *"There is not enough space because the building is small even if you say we should have more staff the rooms will not be enough. But the staff are not enough as well but we are doing our best"* Participant 10, Health Center.

Providers added that integration might increase their workload, which could subsequently compromise the quality of care currently provided at the HIV CTC and extend patient waiting times.

> *"It will not be difficult in such but there will be more work for all of us including the pharmacist, he must spend more time on dispensing other medication"* Participant 3, Regional Referral Hospital.

> *"Difficulty could be with buying medications and staff because we are not only dealing with HIV, clients with NCDs will also need to see a doctor so it can be exhausting and also jeopardize efficiency."* Participant 4, Regional Referral Hospital.

Providers also emphasized that successful integration requires ensuring the availability of all necessary equipment (BP machines,

glucometers, and RBG strips), diagnostic tests (blood chemistry), and medications. Such resources are currently lacking at the HIV CTCs.

> *"We have no equipment like RBG machines, but it would be good if we had the machine, if we find a symptomatic client we link them with the NCD clinic at OPD"* Participant 1, District Hospital.

Regarding *access to information and knowledge,* half of the providers reported receiving training on CVD comorbidities management, mostly from regional referral and District Hospitals. The remaining half reported not being trained in NCD management, being unaware of the current recommendations, and not having guidelines for managing these conditions. These providers rely on physicians from the NCD clinics for guidance on managing CVD comorbidities and refer patients to them for treatment.

> *"Okay, apart from the knowledge I got from school long ago, I received this 'crash training," maybe we remind each other in meetings on the first or second-line management of hypertension. But if I am worried, I will consult the physician from there (NCD clinic) since he is more experienced, I describe the client's case and I get advised on how to proceed"* Participant 1, District Hospital.

Characteristics of individuals

Two constructs under the characteristics of individuals were explored. These were *knowledge and belief about intervention and self-efficacy.*

> Related to *knowledge and belief about the intervention*, providers expressed their willingness and motivation to provide CVD care alongside HIV care, despite a potential increase in workload, and the existing challenges of staff shortages and limited space at the HIV CTC.
>
> *"Yes, it's something that I wish for to happen because it's good to know the outcome when you are taking care of a patient, but if you only give ART and this patient is hypertensive and diabetic, he will take the ART, but what about the other aspects that you were not able to help him with?"* Participant 3, Regional Referral Hospital.

Regarding *self-efficacy*, providers reported that their long-standing focus has primarily been on HIV care, ART adherence, and viral suppression. Although they are confident in their ability to screen for CVD comorbidities, they reported the need for training, particularly on current management recommendations for these comorbidities.

> *"I would request refresher training, regarding the new guidelines. They should send new employees for training or do on job training. Guidelines will also assist in making diagnoses and choices of treatment. There should be regular refresher training and mentorship which will help a lot"* Participant 6, Health Center.

Discussion

We conducted a qualitative study with 12 HIV CTC providers at three diverse healthcare facility levels to understand the barriers and facilitators to the integration of CVD care within the usual HIV care in urban Tanzania. The major barriers to integrating CVD care in HIV CTCs identified in this study were related to the inner setting domain. Providers reported a lack of resources to provide CVD care alongside HIV care within HIV CTCs. These resources included (functioning) equipment for screening CVD comorbidities (BP machines and glucometers), trained human resources on CVD comorbidities management, and electronic data capturing tool for monitoring CVD comorbidities management and outcomes. Qualitative studies of integrated HIV and CVD care in SSA reported similar challenges (26, 28, 39, 40).

One additional barrier that was reported among providers in our study that was not reported in previous studies is the fear of increased workload after HIV/CVD care integration. Providers in this study expressed their concerns about HIV CTCs becoming overwhelmed again, as they were before the introduction of MMD. Integrating CVD care into HIV CTCs may potentially overburden providers and lead to congestion at these clinics (41). Ministry of Health needs to obtain effective buy-in from providers before integration, as the integration of HIV and CVD care might increase their workload. However, clients with controlled CVD risk factors such as hypertension and diabetes can also be seen for up-to 6 months if their comorbidities are well controlled, and the supply chain allows for multi-month prescribing for CVD risk factors medications. With good medication adherence and self-management strategies, clients will eventually transition to MMD for CVD risk factors management, just as they did for HIV. In previous research, HIV CTC providers were reported to be less willing to provide CVD care, citing that CVD care is not the traditional role of an HIV CTC provider (42). It is essential to engage the HIV CTC providers in the planning process for HIV/CVD integration to ensure that all concerns are addressed before moving forward with the integration.

Providers from lower-level health facilities, particularly Health Centers, reported a lack of space to provide both CVD and HIV care simultaneously. This was not the case for Regional Referral Hospitals. This suggests that higher-level health facilities may be better suited for initial small-scale implementation science trials to assess implementation and clinical outcomes of HIV/CVD integrated care, informing the design of an effective and sustainable model in Tanzania. Future research can focus on developing implementation strategies based on our study findings and evaluating a context-appropriate HIV/CVD integrated care model.

Although HIV care in Tanzania, including doctor consultations and medication, is provided for free, care for CVD comorbidities is not. Providers stated that without providing CVD care for free for ALHIV including medications, integrated care may not yield significant benefits. Provision of free medication may motivate clients to remain in CVD care, however, the long-term sustainability of this approach is a concern. Research has also shown provision of free CVD comorbidities medication as a component of HIV/CVD integrated care, may not necessarily improve clinical outcomes (43). Our previous study exploring experiences with hypertension and diabetes management found that there is intermittent medication use for these conditions among ALHIV. Beyond medication cost, this was due to negative perception regarding CVD risk factor medications. They reported fears of side-effects associated with the life-long use of hypertension and diabetes medication alongside HIV treatment, and the perceptions that medications for these conditions are ineffective

(24). Successful integration with positive clinical outcomes requires efforts beyond providing free medication, including regular monitoring of patients, medication adherence, and lifestyle counseling (44). The exploration of financing options for integrated HIV/CVD care among HIV CTC providers was beyond the scope of this study. Our future plan is to engage policy makers at the Ministry of Health and implementing partners to understand existing plans for financing CVD care at the HIV CTCs. This understanding is critical for informing design and testing of the integrated HIV/CVD care.

Despite the reported barriers, our study identified a number of facilitators that could support a successful HIV/CVD care integration in Tanzania. HIV CTCs in our study reported that the implementing partner (MDH) has started to support CVD care within their HIV CTCs. MDH provides BP machines and monitors, trains healthcare workers on NCD management, and ensured that BP is among the indicators recorded and monitored at the HIV CTCs. With this support, there is now more screening for hypertension in these HIV CTCs compared to the past, and those diagnosed are being monitored. This facilitating factor is among the factors that was not reported by the previous study in this setting (26). These initiatives establish a strong foundation for integration. Scaling up to include other CVD comorbidities, such as diabetes, and replicating these efforts among other implementing partners across Tanzania is essential.

HIV CTC providers in our study maintained a positive attitude toward integrating CVD care into the HIV CTCs and did not consider it a complex task. Providers acknowledged the growing need for CVD comorbidities care among their clients and reported being motivated to meet this need. A previous study in Tanzania also reported the presence of a health workforce willing to provide CVD care at the HIV CTCs (26). The availability of a motivated healthcare workforce ready to provide integrated care offers a valuable opportunity for the Ministry of Health, and other stakeholders in Tanzania, to establish the necessary environment for integration. There is a growing body of evidence that integrating CVD care within HIV CTCs is feasible in SSA (13, 14). The guideline for the management of HIV in Tanzania also recommends the provision of CVD care at HIV CTCs (24). However, integrating care without adequate resources may compromise the quality of the existing HIV care (45).

Strengths and limitations

This study systematically explores barriers and facilitators to integrating CVD care within HIV CTCs using an implementation science framework (CFIR). This approach enhances cross-study comparisons and enables systematic mapping of implementation strategies and designing of an integrated model using implementation science research approaches (46). We involved three different healthcare levels (Regional Referral Hospitals, District Hospitals, and Health Centers) and identified variations in barriers and facilitators by these levels. However, the study had a few limitations. Firstly, the six HIV CTCs recruited in this study are supported by the same implementing partner and are in urban settings. As a result, our findings may have limited generalization to HIV CTCs supported by other implementing partners who might be providing different types or levels of support to their HIV CTCs. Future research could purposively select HIV CTCs supported by different implementing partners in Tanzania to explore variations in the level of support provided for CVD care. Findings presented in this paper include only providers' perceptions of the factors that could influence the integration of CVD care at HIV clinics and lack representation of patients' voices. However, the experiences, perceptions and preferences of ALHIV regarding HIV/CVD care integration that could potentially influence integration have been described in our previous publication (24).

Conclusion

In parallel with ongoing efforts to implement the provision of CVD care within HIV CTCs in Tanzania, this study highlights key barriers including lack of equipment, lack of space, unavailability of an electronic data-capturing tool for monitoring CVD outcomes, and a shortage of trained healthcare workers. The barriers should be considered when designing a context-relevant HIV/CVD integrated care model for ALHIV, leveraging existing resources and facilitators within the HIV CTCs.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Muhimbili University of Health and Allied Sciences (MUHAS) MUHAS-REC-08-2020-343, National Institute for Medical Research (NIMR)-NIMR/HQ/R8a/VOL.IX/3513, and Northwestern University (STU00214283) ethics committees. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

TO: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. FN: Data curation, Formal analysis, Methodology, Writing – review & editing. ZB: Conceptualization, Methodology, Writing – review & editing, Validation. CH: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Supervision, Writing – review & editing. SK: Conceptualization, Methodology, Supervision, Writing – review & editing. EM: Data curation, Formal analysis, Methodology, Writing – review & editing. PC: Conceptualization, Supervision, Writing – review & editing. HS: Conceptualization, Methodology, Writing – review & editing. LH: Conceptualization, Data curation, Formal

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Conflict of interest

ZB was employed by the company Phreesia, Inc.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2024.1483476/full#supplementary-material

SUPPLEMENTARY FILE 1
COREQ checklist.

SUPPLEMENTARY FILE 2
Interview guide.

SUPPLEMENTARY FILE 3
Barriers and facilitators to integration of CVD care at HIV CTCs in Dar es Salaam, Tanzania 2022.

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Preventable hospitalizations through ED: does the number of hospital beds matter under the global budget in a single-payer system in Taiwan?

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Background: Taiwan implemented global hospital budgeting with a floating-point value, which created a prisoner's dilemma. As a result, hospitals increased service volume, which caused the floating-point value to drop to less than one New Taiwan Dollar (NTD). The recent increase in the number of hospital beds and the call to enhance the floating-point value to one NTD raise concerns about the potential for increased financial burden without adding value to patient care if hospitals expand their bed capacity for volume-based competition. The present study aimed to examine the relationship between the supply of hospital beds and hospitalizations following an emergency department (ED) visit (called ED hospitalizations) by using diabetes-related ambulatory care sensitive conditions (ACSCs) that are preventable and discretionary as an example.

Methods: The study was a pooled cross-sectional design analyzing 2011–2015 population-based claims data in Taiwan. The dependent variable was a dummy variable representing an ED hospitalization, with a treat-and-leave ED visit as the reference group. The key independent variable is the number of hospital beds per 1,000 populations. Multivariate logistic regression models with and without a clustering function were used for the analyses.

Results: Approximately 59.26% of diabetes-related ACSCs ED visits resulted in ED hospitalizations. The relationship between the supply of hospital beds and ED hospitalizations was statistically significant (OR = 1.12; 95% CI: 1.09–1.14; $P < 0.001$) in the model without clustering but was statistically insignificant in the model with clustering (OR = 1.03; 95% CI: 0.94–1.12; $P > 0.05$). Several social risk factors were positively associated with the likelihood of ED hospitalizations, such as low income and the percentage of the population without a high school diploma. In contrast, other factors, such as female patients and the Charlson comorbidity index, were negatively associated with the likelihood of ED hospitalizations.

Conclusion: Under hospital global budgeting with a floating-point value mechanism, increases in hospital beds likely motivate hospitals to admit ED patients with preventable and discretionary conditions. Our study emphasizes the urgent need to add value-based incentive mechanisms to the current global budget payment. The value-based incentive mechanisms may encourage providers to focus on quality of patient care by addressing social risk factors

rather than engage in volume-based competition, which would improve population health while reducing preventable ED visits and hospitalizations.

KEYWORDS

ambulatory care sensitive conditions, treat-and-leave emergency department visits, global budget, preventable hospitalizations, diabetes-related complications, floating-point value

Introduction

Hospital expenditure is the largest share of total healthcare spending in many countries (1, 2). Payers have used hospital global budgeting to contain escalating expenditures by sharing financial accountability with hospitals and encouraging hospitals to work with other providers to reduce unnecessary care or preventable hospitalizations (3–6). There are different forms of global budgeting. For example, the Maryland Total Cost of Care Model in the United States implemented a global budget without price adjustments for each service, while Taiwan and Germany implemented a global budget with price adjustments (7). The variations in global budgeting would likely affect providers' behaviors differently.

In 1995, Taiwan implemented the national health insurance (NHI) program with a single-payer system, operated by the National Health Insurance Administration (NHIA). At the beginning of NHI, providers were paid by the fee-for-service payment system. Because of the fast-growing health expenditure, the NHIA adopted the global budget payment with price adjustments through a floating-point value mechanism and gradually applied the payment to dental, Chinese medicine, and Western medicine in clinics and hospitals in 1998, 2000, 2001, and 2002, respectively. The amount of the global budget nationally depends on the total expenditure in the previous year, the change in population characteristics and providers' operating costs, the growth of the economy, and policies, such as care for high-risk populations and remote areas (8).

The features of the global budget payment with a floating-point value mechanism in Taiwan are a mixed prospective and retrospective payment. The amount of budget to pay providers is predetermined before the start of the calendar year, which is prospective. A floating-point value is equivalent to the total predetermined budget divided by the total service volume rendered by all providers in the market, which is retrospective. Using the hospital industry as an example, an individual hospital's total payment is a floating-point value multiplied by the total service volume delivered by the hospital. Given a floating-point value mechanism, hospitals do not know their total payment until the NHIA counts the service volume from all hospitals and calculates a floating-point value per service volume.

Hospital global budgeting with a floating-point value mechanism creates the phenomenon called prisoner's dilemma to hospitals (9, 10), because the total payment to an individual hospital depends on the volume of services provided by the hospital and other hospitals in the same market. Ideally, it would be good if all hospitals agreed to produce a specific volume to keep a floating-point value at their desired value. However, an individual hospital is unlikely to know the other hospitals' service volume; therefore, an individual hospital is willing to increase its service volume to secure its share from the predetermined budget. Empirical evidence from Taiwan showed that, in response to the challenges of prisoner's dilemma, hospitals engaged in volume-based competition. This included increasing services with high price/cost margins (e.g., radiology), as well as boosting the number of prescriptions, procedures, and length of stays (9–11). Due to volume-based competition, the floating-point value was, on average, less than one New Taiwan Dollar (NTD).

Hospitals may also increase their capacities, allowing them to compete with others regarding service volume. Recently, medical centers and chain hospitals in Taiwan have expanded the number of hospital beds. More than 3,000 new hospital beds are either under reconstruction or have been approved and will soon enter the market, reaching 4.5 hospital beds per 1,000 populations. This would be higher than the average of 4.3 hospital beds per 1,000 populations in the Organization for Economic Cooperation and Development (OECD) countries (12). However, evidence regarding the association between the supply of hospital beds and hospitalization rates, especially for emergency department (ED) hospitalizations under the global budget with the price adjustment payment system, is limited.

The present study aimed to examine the association between the supply of hospital beds and ED hospitalizations. We chose diabetes-related ambulatory care sensitive conditions (ACSCs) as an example because ED hospitalizations due to diabetes-related ACSCs are preventable and discretionary. Defined by the Prevention Quality Indicators (PQI) program in the Agency for Healthcare Research and Quality (AHRQ), diabetes-related ACSCs include short-term complications (e.g., ketoacidosis with/without coma), long-term complications (e.g., diabetic nephropathy or retinopathy), uncontrollable diabetes (hypo/hyper-glycemia with or without coma), and lower-extremity amputation. Hospitalizations due to those conditions are theoretically preventable if patients can receive proper care in the community. Furthermore, there is a high variation in ED physicians' decisions regarding ED admissions, which cannot be explained by patients' clinic conditions (13–15). Thus, ED hospitalizations due to diabetes-related ACSCs are considered discretionary.

Significance of the study

The concept of "supply induces demand" is commonly supported by studies based on the fee-for-service payment system, activity-based payment, or diagnosis-related group (DRG) payment (16–22). However, the results of ED hospitalizations are mixed. For example, in England, O'Cathain et al. (21) examined a broad definition of preventable hospitalizations (e.g., cellulitis and injury)

at the hospital level and found that the supply of hospital beds was positively associated with the likelihood of ED hospitalizations. By using all ED conditions, the study from Sweden showed that ED patients were likely to be hospitalized when hospital beds were available (14); however, the study from the Medicare fee-for-service population in the United States showed a negative association between the supply of hospital beds and ED hospitalizations (22, 23). As many countries have moved payment systems away from the fee-for-service payment toward a global budget payment (14, 24), testing a theoretical assumption about the prisoner's dilemma by utilizing preventable and discretionary conditions is needed.

With the challenge of unpredictable revenue under the predetermined budget payment with price adjustments through a floating-point value mechanism, hospitals in Taiwan provide a good case to test the theoretical assumption (9, 10). Based on previous evidence in Taiwan (9–11, 25), we hypothesized a positive association between the supply of hospital beds and the likelihood of ED hospitalizations for preventable and discretionary conditions. Most importantly, the NHIA in Taiwan faces a significant challenge from providers that call for enhancing the budget to pay hospitals by increasing a floating-point value from less than 1 NTD to 1 NTD. If the supply of hospital beds is positively associated with discretionary and preventable hospitalizations, increasing the floating-point value would increase the financial burden on the NHIA without adding the value of care for patients. The findings in the present study could have important implications for healthcare policies.

Materials and methods

Data sources

The present study used six data sources: (1) the 2011–2015 National Health Insurance Research Database (NHIRD), (2) the Medical Care Institution file, (3) the Ministry of Interior Global Information Network (GIN), (4) the Taiwan Medical Association, and (5) DATA.GOV.TW, a platform that comprises various data at the township and district levels. The NHIRD provided enrollment and inpatient and outpatient claims data at the patient level. The enrollment file provides the insured's sociodemographic characteristics and residential locations. The inpatient and outpatient claims data that provide the International Classification of Disease 9th Revision, Clinical Modification (ICD-9-CM) for up to three diagnoses and procedures were used to identify ED hospitalizations and patients who were discharged from ED (hereafter called treat-and-leave ED visits) due to diabetes-related ACSCs, respectively. The Medical Care Institution File provides information on whether patients received care at medical centers, regional hospitals, or local hospitals. The GIN provides data concerning the number of individuals with different levels of education and the number of Aboriginginal people in each township. The Taiwan Medical Association provides the number of physicians in the workforce. Finally, DATA.GOV.TW provides the number of hospital beds at the township/district level.

Study design and study sample

The study design was a pooled cross-sectional study using data from 2011 to 2015. We selected this period because the NHIRD started providing the code of ED hospitalizations in the "Patient_source" starting in 2011, and diagnosis codes were coded by ICD-9-CM prior to 2016. The study sample was ED hospitalizations (extracted from inpatient files) and treat-and-leave ED visits (extracted from outpatient files) for individuals aged 20 and above with diabetes-related ACSCs. We applied the ICD-9-CM codes listed by the AHRQ PQI program to identify hospitalizations and ED visits due to diabetes-related ACSCs. We excluded observations with missing data in residential locations and institutions. For the ED hospitalization group, the observations without the code "Patient_source" as ED were excluded. We then merged the ED hospitalizations and treat-and-leave ED visits to form the study sample in the present study. The selection process of the study sample is shown in Figure 1.

Variable measures

Dependent variables

ED hospitalizations due to diabetes-related ACSCs

Figure 1 shows two groups of patients—ED hospitalizations and treat-and-leave ED visits—in the study sample. We created a dichotomous variable for observations with ED hospitalizations, with observations in the treat-and-leave ED visits group as the reference group.

Key independent variable

The key independent variable is the supply of hospital beds, which is measured as a continuous variable by the number of general hospital beds per 1,000 populations at the township/district level.

Control variables

Based on the ACSC-related literature, the likelihood of ED hospitalizations is associated with patients' health conditions and the context of organizations and communities (13, 14, 22, 26–28). Thus, these variables were included in the analytical models. Patient characteristics included age (50–64, 65–79, and 80+, with 20–49 as the reference group), sex (female, with male as the reference group), ethnicity, low income, education level, and the Charlson comorbidity index (29). Ethnicity was proxied by a dummy variable representing the townships/districts with the percentage of Aboriginal people at the 75 percentile and above. A dummy variable measured low-income status if individuals qualified for free premiums. Education was proxied by the percentage of the population without a high school diploma at the township/district level. Organization factors included two dummy variables: regional and local hospitals, with medical centers as the reference group. Community characteristics included the number of primary care physicians per 1,000 populations and two dummy variables representing rural and suburban areas, with urban as the reference group based on the findings from Liu et al.'s (30) study. Finally,

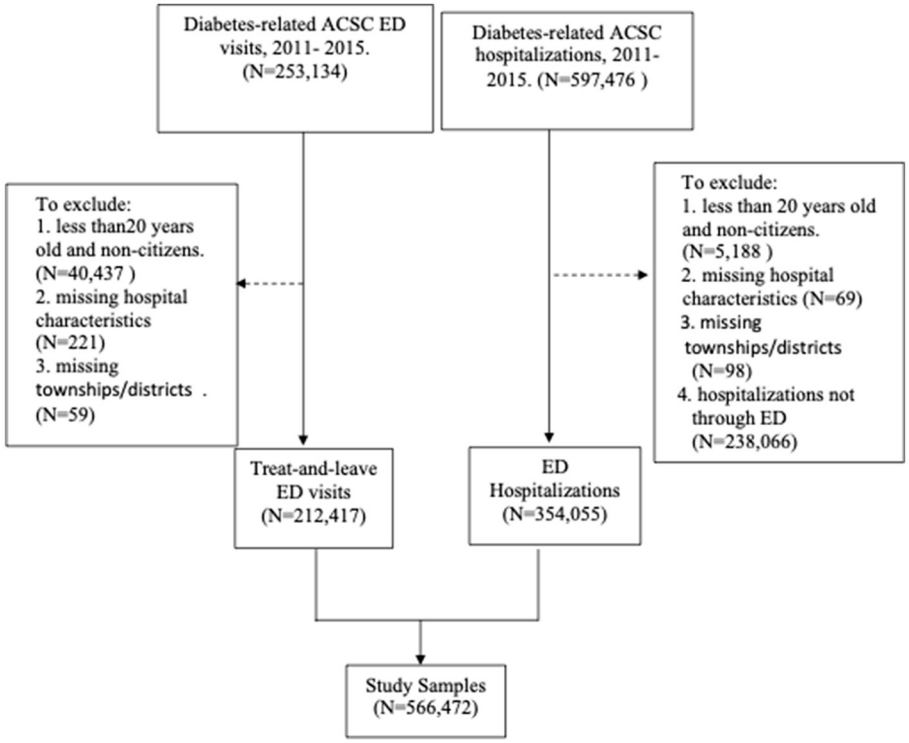


FIGURE 1
Flow chart of the selection process for the study sample.

we also added year dummies, with 2010 as the reference group to capture potential changes due to time.

Analytical approach

We conducted *t*-tests for continuous variables and chi-squared tests for categorical variables to compare the differences in study variables between ED hospitalizations and treat-and-leave ED visits. To observe the likelihood of ED hospitalizations associated with the supply of hospital beds, we applied multivariate logistic regression models with ED visits as the unit of analysis. We gradually added the characteristics of patients, hospitals, and communities. Theoretically, the likelihood of ED hospitalizations is affected by hospital policies, the ED's crowdedness, and the community's context (e.g., resources and support systems), which cannot be completely measured in the current study (13, 15, 23, 31). To consider these contextual factors, we conducted sensitivity analyses with clustering patients at the hospital and community levels. A *P*-value of <0.05 is considered significant. Statistical analyses were performed using SAS v 9.4 (SAS Institute, Cary, NC).

Results

In the 2011–2015 outpatient files, we identified 253,134 ED visits due to diabetes-related ACSCs. After excluding patients aged under 20 years or non-citizens ($N = 40,437$), those with missing township/district data ($N = 59$), and those with missing hospital information for ED visits ($N = 221$), the total number of ED visits included in the analytical model was 212,417. In the 2011–2015 inpatient files, we identified 597,476 diabetes-related ACSCs admissions. We excluded patients aged under 20 years or non-citizens ($N = 5,188$), hospitalizations not through ED ($N = 238,066$), patients with missing township/district data ($N = 98$), and missing hospital information ($N = 69$). The total number of ED hospitalizations was 354,055. After merging the qualified sample from the inpatient and outpatient files, the final study sample used in the study was 566,472. Figure 1 presents the selection process of the study sample.

Table 1 presents the descriptive statistics of the study variables between ED hospitalizations and treat-and-leave ED visits. The ED hospitalization rate was ~59.26% (354,055/597,476 in Figure 1). The differences in all the study variables between treat-and-leave ED visits and ED hospitalizations were significant ($P < 0.05$). The number of hospital beds per 1,000 populations in the treat-and-leave ED group was 0.45, while in the ED admission group, it was 0.59. However, the differences in certain variables (e.g., low income or Aboriginal status) between the two groups were small but significant, which is likely due to the large number of observations in the present study. For example, the ED hospitalization group included 3.96% low-income patients and 19.67% Aboriginal individuals, while the treat-and-leave ED visit group had 3.47% low-income patients and 20.91 % Aboriginal individuals ($P < 0.001$). Surprisingly, the average Charlson comorbidity index was slightly higher in the treat-and-leave ED group (4.48) than in the ED hospitalization group (4.05). Regional hospitals had ~48% of the

TABLE 1 Descriptive statistics between treat-and-leave ED visits and hospitalizations through ED due to diabetes-related ACSCs (percentage in the parenthesis).

Study variables	Treat-and-leave ED (n = 214,417)	Hospitalizations through ED (n = 354,055)	P-value
Key independent variable			
Hospital beds per 1,000 populations[a]	0.45 ± 0.60	0.59 ± 0.09	<0.001***
Years			
Year 2011	43,236 (20.35%)	75,697 (21.38%)	<0.001***
Year 2012	42,715 (20.11%)	72,942 (20.60%)	
Year 2013	41,312 (19.45%)	68,221 (19.27%)	
Year 2014	42,551 (20.03%)	68,080 (19.23%)	
Year 2015	42,603 (20.06%)	69,115 (19.52%)	
Individual factors			
Aged 20–49	29,636 (13.95%)	42,578 (12.03%)	<0.001***
Aged 50–64	59,994 (28.24%)	96,529 (27.26%)	
Aged 65–79	75,810 (35.69%)	129,302 (36.52%)	
Aged 80+	46,977 (22.12%)	85,646 (24.19%)	
Female	104,005 (48.96%)	172,040 (48.59%)	0.007**
Male	108,412 (51.04%)	182,015 (51.41%)	
Township with high number of Aboriginal people (≥75th P)	44,427 (20.91%)	69,637 (19.67%)	<0.001***
Township with low number of Aboriginal people (<75th P)	167,990 (79.09%)	284,418 (80.33%)	
Low income	7,371 (3.47%)	14,022 (3.96%)	
Percentage of population without a high-school diploma[a]	0.30 ± 0.10	0.31 ± 0.10	
Charlson comorbidity index[a]	4.48 ± 2.49	4.05 ± 2.59	
Hospital characteristics			
Regional hospital	102,097 (48.06%)	18,5334 (52.35%)	<0.001***
District hospital	47,910 (22.55%)	77,164 (21.79%)	
Medical center	62,410 (29.38%)	91,557 (25.86%)	
Community characteristics			
Primary care physicians per 1,000 populations[a]	0.08 ± 0.10	0.08 ± 0.09	<0.001***
Rural	92,786 (43.68%)	144,596 (40.84%)	
Suburban	92,276 (43.44%)	155,440 (43.90%)	
Urban	27,355 (12.88%)	54,019 (15.26%)	

[a]Mean and standard deviation in the parenthesis.
*P < 0.05.
**P < 0.01.
***P < 0.001.

treat-and-leave ED visit group and 52% of the ED hospitalization group.

Table 2 shows the results of four models without clustering. Model 1 includes the number of hospital beds per 1,000 populations and dummy variables for the years 2012–2015 only. Models 2 to 4 are based on Model 1 by gradually adding the characteristics of patients, hospitals, and communities. The odds ratio of the number of hospital beds per 1,000 populations in Model 1 was less than one and significant (OR = 0.94, 95% CI: 0.94–0.95; $P < 0.001$). However, in Models 2 and 3, the odds ratios were greater than one and insignificant (OR = 1.01 for both models, 95% CI: 0.99–1.02 in Model 2, and 95% CI: 1.00–1.02 in Model 3; $P > 0.05$). In Model 4 that is the full model, the odds ratio of the number of hospital beds per 1,000 populations was significant (OR = 1.12, 95% CI: 1.09–1.14; $P < 0.001$), indicating that after controlling for covariates, increases in one hospital bed per 1,000 populations are associated with increases in 12% likelihood of ED hospitalizations. Table 3 shows the results of four models with clustering at the hospital and community levels. The odds ratio of the number of hospital beds per 1,000 populations in Models 1–4 was similar to that in Table 2, except for the one in Model 4, which is statistically insignificant (OR = 1.03, 95% CI: 0.94–1.12; $P > 0.05$).

TABLE 2 Logistic regression for hospital beds and ED admissions due to diabetes-related ACSCs, without clustering.

	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)	Model 4 (full model) OR (95% CI)
Key independent variable				
Hosp beds per 1,000 populations	**0.94*** (0.94, 0.95)**	**1.01 (0.99, 1.02)**	**1.01 (1.00, 1.02)**	**1.12*** (1.09, 1.14)**
Years				
Year 2012	0.98** (0.96, 0.99)	0.99 (0.97, 1.01)	0.99 (0.97, 1.01)	0.99 (0.97, 1.00)
Year 2013	0.94*** (0.93, 0.96)	0.96*** (0.95, 0.98)	0.96*** (0.94, 0.98)	0.96*** (0.94, 0.97)
Year 2014	0.91*** (0.90, 0.93)	0.94*** (0.92, 0.95)	0.93*** (0.92, 0.95)	0.93*** (0.92, 0.95)
Year 2015	0.93*** (0.91, 0.95)	0.95*** (0.94, 0.97)	0.95*** (0.94, 0.97)	0.95*** (0.93, 0.96)
Individual factors				
Age (ref.: 20–49)	X			
50–64	X	1.20*** (1.18, 1.23)	1.21*** (1.18, 1.23)	1.21*** (1.18, 1.23)
65–79	X	1.34*** (1.32, 1.37)	1.34*** (1.32, 1.37)	1.34*** (1.32, 1.37)
80+	X	1.45*** (1.43, 1.48)	1.45*** (1.42, 1.48)	1.46*** (1.43, 1.48)
Sex (ref: male)	X	0.95*** (0.94, 0.96)	0.95*** (0.94, 0.96)	0.95*** (0.94, 0.96)
Township with high aborigines (ref: <75th percentile)	X	0.90*** (0.89, 0.91)	0.90*** (0.89, 0.91)	0.89*** (0.87, 0.90)
Low income (ref: non-low income)	X	1.28*** (1.24, 1.32)	1.27*** (1.23, 1.31)	1.27*** (1.23, 1.31)
Percentage of individuals without a high school diploma	X	2.51*** (2.35, 2.69)	2.35*** (2.19, 2.51)	1.75*** (1.61, 1.91)
Charlson comorbidity index	X	0.93*** (0.93, 0.93)	0.93*** (0.93, 0.93)	0.93*** (0.93, 0.93)
Hospital characteristics				
Regional hospital (ref: Medical center)	X	X	1.20*** (1.19, 1.22)	1.20*** (1.18, 1.22)
District hospital (ref: Medical center)	X	X	1.05*** (1.04, 1.07)	1.04*** (1.03, 1.06)
Community characteristics				
Primary care physicians per 1,000 populations	X	X	X	0.43*** (0.36, 0.50)
Suburban (ref: urban)	X	X	X	0.99 (0.97, 1.00)
Rural (ref: urban)	X	X	X	1.11*** (1.08, 1.14)

*P < 0.05.
**P < 0.01.
***P < 0.001.

The odds ratios among covariates in the full models with and without clustering are similar. The odds ratios for the years 2013–2015 were less than one and significant (OR: 0.93–0.96, 95% CI: 0.91–0.99; $P < 0.001$), indicating that the likelihood of ED hospitalizations was lower than that in the year 2011. The odds ratios of the three age dummies (50–64, 65–79, and 80+, with < 50 as the reference group) ranged from 1.21 to 1.45 (95% CI: 1.18–1.50; $P < 0.001$). Female patients were less likely to have ED hospitalizations than male (OR = 0.95, 95% CI: 0.94–0.96; $P < 0.001$). Patients with low income (OR: 1.17–1.27; 95%CI: 1.14–1.31; $P < 0.001$) or without a high school diploma (OR: 1.46–1.75; 95%CI: 1.16–1.91; $P < 0.001$) had a higher likelihood of ED hospitalizations than their counterparts. Regional and district hospitals had a higher likelihood of ED hospitalizations than medical centers (OR: 1.04–1.20, 95% CI: 1.03–1.22; $P < 0.001$). However, the odds ratio of Aboriginal individuals, the number of primary care physicians per 1,000 populations, and rural areas were significant in the model without clustering but became insignificant in the model with clustering. Unexpectedly, the odds ratio of the Charlson comorbidity index showed that increases in the index were negatively associated with the likelihood of ED admissions (OR = 0.93–0.94; 95%CI: 0.93–0.94; $P < 0.001$).

Discussion

Summary of the findings

Our study revealed a positive relationship between the supply of hospital beds and the likelihood of ED hospitalizations due to diabetes-related ACSCs; however, the association was statistically significant without a clustering function but was statistically insignificant with a clustering function after controlling for covariates. Among all covariates, the odds ratios in several variables in the models with and without clustering were consistent. Notably, variables with odds ratios higher than one and statistical significance included age groups, low income, a percentage of individuals without a high school diploma, and regional and district hospitals. Conversely, variables with odds ratios of less than one

TABLE 3 Logistic regression for hospital beds and ED admissions due to diabetes-related ACSCs, with clustering patients at the hospital and community level.

	Model 1	Model 2	Model 3	Model 4 (full model)
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Key independent variable				
Hosp beds per 1,000 populations	**0.95*** (0.92, 0.97)**	**0.99 (0.95, 1.03)**	**0.99 (0.95, 1.03)**	**1.03 (0.94, 1.12)**
Years				
Year 2012	0.97* (0.95, 0.99)	0.98 (0.96, 1.00)	0.98 (0.96, 1.00)	0.98 (0.96, 1.00)
Year 2013	0.95*** (0.92, 0.98)	0.96* (0.93, 0.99)	0.96* (0.93, 0.99)	0.96** (0.93, 0.99)
Year 2014	0.94*** (0.90, 0.97)	0.95** (0.91, 0.98)	0.95** (0.91, 0.98)	0.95** (0.91, 0.98)
Year 2015	0.94** (0.91, 0.98)	0.96* (0.92, 0.99)	0.96* (0.92, 0.99)	0.95* (0.91, 0.99)
Individual factors				
Age (ref.: 20–49)	X			
50–64	X	1.19*** (1.17, 1.22)	1.19*** (1.17, 1.22)	1.19*** (1.17, 1.22)
65–79	X	1.32*** (1.29, 1.35)	1.32*** (1.29, 1.35)	1.32*** (1.29, 1.35)
80+	X	1.45*** (1.41, 1.50)	1.45*** (1.41, 1.50)	1.45*** (1.41, 1.50)
Sex (ref: male)	X	0.95*** (0.94, 0.96)	0.95*** (0.94, 0.96)	0.95*** (0.94, 0.96)
Township with high aborigines (ref: <75th percentile)	X	0.99 (0.94, 1.04)	0.99 (0.94, 1.04)	0.98 (0.93, 1.04)
Low income (ref: non-low income)	X	1.17*** (1.14, 1.21)	1.17*** (1.14, 1.21)	1.17*** (1.14, 1.21)
Percentage of individuals without a high school diploma	X	1.68*** (1.40, 2.02)	1.69*** (1.41, 2.03)	1.46*** (1.16, 1.84)
Charlson comorbidity index	X	0.94*** (0.94, 0.94)	0.94*** (0.94, 0.94)	0.94*** (0.94, 0.94)
Hospital characteristics				
Regional hospital (ref: Medical center)	X	X	1.17*** (1.12, 1.22)	1.17*** (1.12, 1.22)
District hospital (ref: Medical center)	X	X	1.13*** (1.08, 1.19)	1.13*** (1.08, 1.19)
Community characteristics				
Primary care physicians per 1,000 populations	X	X	X	0.84 (0.45, 1.57)
Suburban (ref: urban)	X	X	X	1.05 (1.00, 1.12)
Rural (ref: urban)	X	X	X	1.07 (0.99, 1.15)

*P < 0.05.
**P < 0.01.
***P ≤ 0.001.

and statistical significance included dummies for study years, sex (female), and the Charlson comorbidity index.

Comparison with other studies

Although some programs in the United States and several countries gradually adopted a global budget to pay providers (32), evidence primarily focuses on the effect of a global budget on service volume or expenditure. In the United States, Massachusetts State adopted the Alternative Quality Contract (AQC), and Maryland State adopted the Maryland Total Cost of Care Model, a global budget with providers keeping the margin and incentivizing for quality of care. Both models reduced utilizations (e.g., laboratory tests and ED hospitalizations and visits) while improving quality of care (e.g., tobacco cessation and the tests of glycated hemoglobin and cholesterol for chronic disease management) (5, 33–39). The Centers for Medicare and Medicaid Services launched different types of accountable care organizations that are responsible for managing a patient population within a capped budget. Findings showed that accountable care organizations reduced inpatient use and ED visits and improved preventive care and chronic disease management (40). Outside of the United States, physicians in Germany increased their service volume after Germany applied a global budget with price adjustments on ambulatory care (4). In Denmark, hospitals funded via a global budget with value-based incentives were able to reduce the length of stay for inpatients (41).

Literature has shown that the number of hospital beds per 1,000 populations has been reduced in several OECD countries, such as Australia, Canada, Denmark, France, and Sweden, regardless of whether the countries implemented a global budget (41, 42). In the United States, the number of hospital beds per 1,000 populations in Maryland State has been reduced after implementing the Total Cost of Care Model (43). Given the recent rising number of hospital beds per 1,000 populations from 4.3 to 4.5 in Taiwan, the positive findings in our study and the increases in service volume and intensity of care found in previous studies in Taiwan (7, 10, 11,

25) indicate that the likelihood of ED hospitalizations would be increased when hospital beds are available.

In addition to the supply of hospital beds, social determinants, including income and education at the patient level and hospital characteristics at the hospital level, are positively associated with the likelihood of ED hospitalizations. On average, the ED hospitalizations rate in the current study was 59% (597,476/566,472 in Figure 1). Identifying high-risk patients and conducting interdisciplinary collaboration to meet their social and health needs would reduce ED visits and hospitalizations while keeping patients safe at home.

Limitations

The present study has limitations. First, the study used data from 2011 to 2015. The majority of the expanded hospital beds are still under reconstruction. Our findings cannot completely reflect the association when all new hospital beds are available in the market. Furthermore, the NHIA has launched several interventions, such as increasing the differences in co-payment and encouraging mutual referrals among medical centers, district hospitals, and local hospitals to reduce the burden on medical centers and strengthen local hospitals and clinics in the communities. Utilizing the most recent data to investigate the relationship between hospital beds and ED hospitalizations is encouraged. Second, the AHRQ PQI program excludes patients transferred from other institutions or receiving specific procedures. Our data did not have the codes for procedures and transfer from a hospital or other institutions; therefore, the number of diabetes-related ACSCs was likely be overestimated. However, the limitations of missing these variables in the data are unlikely to affect our findings since we applied the same rules to extract diabetes-related ACSCs from inpatient and outpatient files. Third, we assume that hospitals are engaging in the game of prisoner's dilemma. However, hospitals may adjust their ED hospitalizations policy to maximize their margin based on their historical reimbursement data, which cannot be detected by the current study, although the chance is low given the existing evidence from Taiwan (9–11, 25). Finally, the present study focused on diabetes-related ACSCs. Future studies examining other discretionary conditions (e.g., heart failure or asthma) and non-discretionary conditions (e.g., fracture or heart attack) are also recommended.

Policy implications

Despite the limitations, our findings have policy implications. First, the fast-expanding number of hospital beds in recent years may motivate hospitals to admit ED patients with preventable and discretionary conditions under a global budget with a floating-value payment system. Therefore, the call to increase the floating-point value to one NTD would eventually challenge the financial sustainability of the NHI without adding value to patient care. Given the evidence from other countries, adding value-based incentive mechanisms to the current global budget system is strongly recommended. Second, although 99% of the population in Taiwan is enrolled in the NHI, patients with low income and without high school education are at risk of ED hospitalizations due to diabetes-related ACSCs. Policies that effectively address the risks of social determinants contributing to poor health outcomes are strongly recommended, which would have the potential to significantly improve population health while reducing the financial burden on the NHIA.

Conclusion

An increase in the number of hospital beds is likely to motivate providers to admit ED patients with preventable and discretionary conditions under hospital global budgeting with a floating-point value mechanism, which would lead to high hospitalization rates without adding value to patient care. Adding value-based incentive mechanisms to the current global budget payment and addressing social risk factors contributing to poor health outcomes would improve population health and reduce preventable hospitalizations while improving the financial sustainability of the NHI.

Data availability statement

The datasets presented in this article are not readily available because the datasets used and analyzed in the present study are not publicly available but are available from the Taiwan National Health Insurance Program in Taiwan. Restrictions apply to the availability of these data, which were used under license for the present study. Requests to access the datasets should be directed at: https://nhird.nhri.org.tw with the permission of the Taiwan National Health Insurance (NHI) program.

Ethics statement

The studies involving humans were approved by the Institutional Review Board at Kaohsiung Medical University Hospital in Taiwan (KMUHIRB- SV(I)-20210063). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

HFC: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. HMH: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Validation, Writing – review & editing. WSC: Data curation, Formal analysis, Investigation, Software, Validation, Visualization, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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An evaluation study of direct economic losses from surgical site infections in adults: structural equation modeling

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Introduction: Surgical site infection (SSI) represents a significant postoperative complication, resulting in extended hospital stays and substantial economic burdens. Previous research on the direct economic impact of SSIs using recursive systems modeling is limited. This study aims to quantify the direct economic losses attributable to SSIs and to dissect the various factors to these losses.

Methods: A retrospective 1:1 matched case–control study was conducted from January 2023 to March 2024 in three tertiary hospitals in Xinjiang, China. Patients with SSIs were matched on a 1:1 basis by hospital, department, age (±5 years), sex, primary diagnosis, and procedure with controls to form case and control groups. Wilcoxon Signed Ranks Test was utilized to quantify the direct economic loss from SSIs. Influencing factors were analyzed using a recursive system model.

Results: Among the 74,258 patients surveyed, 226 developed SSIs, resulting in an infection rate of 0.3%. The total direct economic loss from SSIs at three hospitals was $467,867, with an average loss of $1,364.37 per SSI patient. SSI patients experienced hospital stays 11 days longer than uninfected patients. Multivariate linear regression identified the duration of hospital stay, catheter and ventilator usage, age, number of surgeries, and duration of antibiotic treatment as influencing factors. Recursive system modeling revealed the indirect contributions of the number of surgeries (indirect effect: 0.074), antibiotic use for 17–36 days (indirect effect: 0.063) and ≥ 37 days (indirect effect: 0.045), and debridement procedures (indirect effect: 0.054), as well as the direct contributions of hospital days (direct effect: 0.276), indwelling catheter days (direct effect: 0.260), ventilator days (direct effect: 0.221), and age (direct effect: 0.182).

Conclusion: Recursive system modeling helped identify the key factors influencing the economic losses from SSIs. These findings provide a theoretical basis for healthcare departments to develop targeted policies.

KEYWORDS

surgical site infections, direct economic loss, recursive system modeling, influencing factors, structural equation

1 Introduction

Surgical site infections (SSIs) rank among the most frequently reported hospital-acquired infections (HAIs). The Center for Disease Control and Prevention (CDC) characterizes SSIs as postoperative infections occurring within 30 days of surgery, or within 1 year if permanent implants are involved. These infections include superficial incisional, deep incisional, and organ/space infections (1). It represents a significant complication for patients post-surgery and poses a major challenge to healthcare-associated infections globally. The three primary HAIs are respiratory infections, urinary tract infections, and SSIs, with the latter leading to readmissions, re-operations, extended antibiotic use, and prolonged hospital stays (2). These infections not only compromise patient health and cause mental stress to patients and their families but also lead to economic losses and resource wastage in the healthcare system.

Currently, the rising number of surgical procedures has elevated SSIs to a critical public health issue (3). The global incidence of SSI is 2.5% (4). Incidence rates are 0.9% in the United States, 3.6% in Australia, 2.9% in China, 2.8% in Africa, and 6.1% in low- and middle-income countries (2, 5–7). A European cohort study (8) revealed an SSI incidence of 5.0%. Direct economic costs of SSIs primarily consist of additional medical expenses and extended hospital stays required for treating these infections (9). A French cohort study reported that the average cost of treating an SSI is approximately €1,814, resulting in annual treatment costs ranging from $10,443 to $25,546 in France (10). In the United States, direct economic losses attributable to SSIs range from $93 million to $112 million annually (11). In Germany, the mortality rate for SSI patients is more than double that of non-infected patients, and the average hospital stay extends by 16 days for those affected by SSIs (12). Studies consistently demonstrate that SSIs are associated with increased costs.

Therefore, it is crucial to understand the hospitalization costs of surgical patients and the factors that influence them in order to manage and mitigate the direct economic losses from SSIs. Structural equation modeling has been increasingly utilized to analyze hospital-acquired infections, particularly hospitalization costs. Studies have demonstrated both direct and indirect relationships between hospitalization costs and influencing factors within a well-defined recursive system structure (13). Using linear regression analysis alone yields only the direct relationships between influencing factors and hospitalization costs, thereby overlooking the complexity and hierarchical nature of each indicator (14). However, the recursive system model in structural equations accounts for all variables in multiple dependent variable equations simultaneously, clearly delineating the complex hierarchical relationships among hospital indicators (15).

Current research lacks studies employing recursive system modeling to analyze the factors influencing the direct economic losses from SSIs. Thus, this paper seeks to identify the key factors for controlling the direct economic losses of SSIs by examining these losses after surgery; analyzing the factors influencing these losses in surgical patients using the recursive system model. This research aims to provide a scientific foundation for health-related departments to develop relevant policies.

2 Methods

2.1 Study design

A retrospective 1:1 matched case–control study without blinding was conducted to collect data on general information, relevant variables, and hospitalization costs of SSI patients from January 1, 2023, to March 31, 2024, at three tertiary hospitals in Xinjiang. Patients with SSI formed the case group, while those without SSIs formed the control group. Matching occurred within the same hospital and department, aligning cases and controls by age (±5 years), sex, primary diagnosis, and procedural consistency. The control group was randomly selected from patients meeting these criteria, and the direct economic losses from SSI was calculated. Risk factors for economic losses of SSI in the matched case group were also analyzed using recursive system modeling.

2.2 Participants

Participants were patients diagnosed with SSI between January 2023 and March 2024 at three tertiary hospitals in a city in Xinjiang. Inclusion criteria were: ① Diagnosis of SSI according to the 2024 CDC NHSN Patient Safety Manual (1); ② Age $\geq$ 18 years; ③ Complete clinical data. Exclusion criteria included: ① Presence of community-acquired infections at admission; ② Pregnancy. This retrospective study received approval from the Ethics Committee of the Fifth Affiliated Hospital of Xinjiang Medical University (approval number XYDWFYSk-2022-12). The committee confirmed that the study conformed to the ethical standards of the 2013 Declaration of Helsinki. Due to the observational nature of this study, informed consent was waived in all participating hospitals. All clinical data were anonymized and de-identified prior to analysis.

2.3 Data collection

Data were retrospectively collected through the hospital infection surveillance systems: HIS system and Apricot Grove system. Collected variables included gender, age, underlying diseases (such as hypertension, diabetes, coronary artery disease, pulmonary disease), number of hospital days, surgeries, days of antimicrobial drug use, pathogen cultures, days of surgical incision drainage, indwelling catheterization, respiratory use, and central venous placement. Hospitalization costs were segmented into categories including total cost, treatment, laboratory, examination, nursing, rehabilitation, general medical services, medicine, surgical blood transfusion, proprietary Chinese medicine and herbal medicine, consumables, and other costs.

2.4 Recursive system model

The recursive system model, a specific type of simultaneous equation model (16), incorporates both endogenous and exogenous variables. Endogenous variables are treated as

dependent, while exogenous variables act as independent variables; exogenous variables influence the model independently, and endogenous variables can also serve as exogenous variables in other equations. Direct effects are exerted by a variable on the dependent variable, and indirect effects are mediated through other variables (16).

$$Y_1 = \gamma_{11} X_1 + \gamma_{12} X_2 + \ldots\ldots + \gamma_{1k} X_k + E_1$$

$$Y_2 = \gamma_{21} X_1 + \gamma_{22} X_2 + \ldots\ldots + \gamma_{2k} X_k + \beta_{21} Y_1 + E_2$$

$$Y_n = \gamma_{n1} X_1 + \gamma_{n2} X_2 + \ldots\ldots + \gamma_{nk} X_k + \beta_{n1} Y_1 + \ldots\ldots + \beta_{n,n-1} Y_{n-1} + E_n \quad (1)$$

Equation 1 outlines the recursive system model where Y is the endogenous variable, X is the exogenous variable, and E is the error term.

2.5 Statistical analysis

SPSS 26.0 software was utilized for statistical analysis. Count data were subjected to normality and chi-squared tests. Non-normally distributed data were presented as median (M) and interquartile range (Q). The differences in hospitalization costs and hospital days between the case and control groups were assessed using a two-independent-samples paired rank sum test (Wilcoxon Signed Ranks Test). Multiple linear regression analyzed the factors influencing the direct economic losses from SSIs. AMOS 26.0 software was used to construct a recursive system model. Non-normally distributed quantitative data required logarithmic transformation, to analyze the factors influencing the direct economic losses of SSI patients. The significance level was set at $\alpha < 0.05$.

3 Results

3.1 Surgical site infection rate and incidence across departments

From January 2023 to March 2024, a total of 74,258 surgical procedures were performed across three hospitals, resulting in 226 SSIs, with an overall postoperative SSI rate of 0.3% (226/74,258). Of these, 21.79% (49/226) underwent debridement. Superficial incision SSIs accounted for 54% (122/226), deep incision SSIs for 35% (79/226), and organ/space SSIs for 11% (25/226), as detailed in Figure 1. Table 1 demonstrates the distribution of SSIs across various surgical departments: orthopedics recorded 86 SSIs out of 22,803 procedures (0.38% SSI rate); cardiac surgery had 9 SSIs from 998 procedures (0.90%); thoracic surgery reported 9 SSIs from 1,936 procedures (0.46%); gynecology had 9 SSIs out of 10,564 procedures (0.09%); neurosurgery had 8 SSIs from 1,339 procedures (0.60%); the breast and thyroid department had 8 SSIs out of 5,179 procedures (0.15%); minimally invasive, hernia, and abdominal wall surgeries reported 6 SSIs from 3,817 procedures (0.16%); gastrointestinal surgery saw 4 SSIs from 2,241 procedures (0.18%); anorectal surgery had 4 SSIs from 2,444 procedures (0.16%); vascular surgery had 4 SSIs from 2,251 procedures (0.18%); maxillofacial surgery reported 3 SSIs from 2,058 procedures (0.15%); hepatobiliary and pancreatic surgery reported 3 SSIs from 3,520 procedures (0.09%); urology reported 3 SSIs from 7,702 procedures (0.04%); emergency trauma surgery saw 2 SSIs from 1,232 procedures (0.16%); plastic and reconstructive surgery had 2 SSIs from 1,594 procedures (0.13%); the Burn Wound Repair Department reported 1 SSI from 1,813 procedures (0.06%); and ophthalmology had 1 SSI from 2,817 procedures (0.04%).

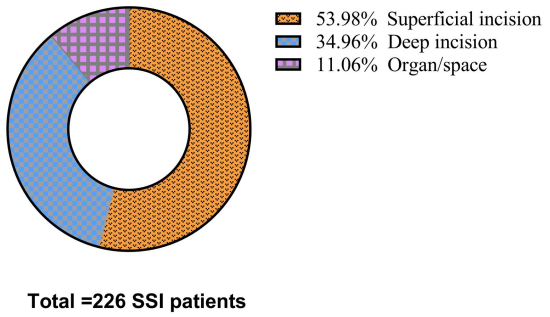


FIGURE 1
Distribution of different infection sited.

TABLE 1 Surgical site infections by department.

Department name	Number of surgeries	Number of SSI	SSI rate (%)
Orthopedics	22,803	86	0.38
Cardiac surgery	998	9	0.90
Thoracic surgery	1,936	9	0.46
Gynecology	10,564	9	0.09
Neurosurgery	1,339	8	0.60
Breast and thyroid surgery	5,179	8	0.15
Minimally invasive, hernia and abdominal wall surgery	3,817	6	0.16
Gastrointestinal surgery	2,241	4	0.18
Anorectal surgery	2,444	4	0.16
Vascular surgery	2,251	4	0.18
Maxillofacial surgery	2,058	3	0.15
Hepatobiliary and pancreatic surgery	3,520	3	0.09
Urology	7,702	3	0.04
Emergency trauma surgery	1,232	2	0.16
Plastic and reconstructive surgery	1,594	2	0.13
Burn wound repair	1,813	1	0.06
Ophthalmology	2,817	1	0.04

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3.2 Direct economic loss of SSI patients

A total of 162 pairs were successfully matched, excluding six minors, five women in labor, one individual with incomplete clinical information, and 52 unmatched cases (no uninfected individuals met the matching criteria of the infected group). As indicated in Table 2, the average direct economic loss per SSI patient was $1,364.37. The rank sum test for all cost categories between the case and control groups revealed no significant differences in rehabilitation costs, costs of proprietary and herbal medicines, and consumable costs; however, significant differences were observed in total hospitalization costs, treatment costs, laboratory tests, examination costs, nursing care costs, general medical service costs, medicine costs, surgical transfusion costs, and other costs ($p < 0.05$). The median hospital stay was 26.5 days for the case group compared to 15 days for the control group, with this difference being statistically significant ($Z = -8.489$, $p < 0.001$). SSI patients experienced a hospital stay 11 days longer than those in the control group.

3.3 Composition ratio of Total direct economic loss for patients with SSIs

Figure 2 illustrates that the total direct economic loss for SSI patients in the three hospitals amounted to $467,867. The breakdown of costs is as follows: $113,487.63 (24.26%) for medications, $111,165.20 (23.76%) for treatments, $69,115.02 (14.77%) for laboratory tests, $56,200.34 (12.01%) for surgical blood transfusions, $46,561.16 (9.95%) for consumables, $30,281.32 (6.47%) for examinations, $18,370.13 (3.93%)

TABLE 2 Various economic losses for SSI (USD).

Sports event	Control subjects	Case group	Difference (the result of subtraction)	*Z*	*p*
	M	*M*	*M*		
Hospital costs	4,814.30	6,623.97	1,364.37	−3.555	<0.001
Treatment costs	471.87	717.33	183.40	−4.018	<0.001
Laboratory costs	385.28	694.26	215.95	−5.343	<0.001
Examination costs	476.70	567.49	101.43	−2.047	0.041
Nursing costs	44.59	90.37	43.96	−7.701	<0.001
Rehabilitation costs	0.00	0.00	0.00	−1.440	0.150
General medical services costs	98.70	189.56	77.98	−7.920	<0.001
Medication costs	312.83	593.23	159.20	−5.256	<0.001
Surgical blood transfusion costs	764.19	1,040.69	179.20	−3.593	<0.001
Cost of proprietary and herbal medicines	16.02	22.97	0.00	−1.613	0.107
Cost of consumables	1,622.88	1,659.79	104.59	−1.233	0.218
Other costs	0.00	0.00	0.00	−2.676	0.007
Days of hospitalization	15.00	26.50	11.00	−8.489	<0.001

SSI is surgical site infection, M is median.

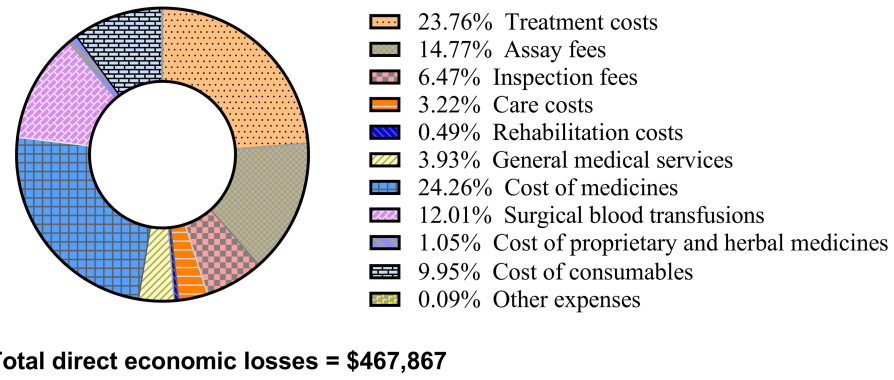


FIGURE 2
Component analysis of surgical site infection direct economic losses.

10.3389/fpubh.2024.1514444

for general medical services, $15,046.69 (3.22%) for nursing care, $4,933.31 (1.05%) for proprietary and herbal medicines, $2,282.56 (0.49%) for rehabilitation, and $401.80 (0.09%) for other expenses.

3.4 Exogenous variable screening results

Age, diabetes mellitus, hypertension, coronary artery disease, pulmonary disease, number of surgeries, debridement surgeries, culture of pathogenic bacteria, days of surgical incision drainage, days of mechanical ventilation, days of central venous catheterization, days of antibiotic use, and days of urethral catheterization (17) were selected as exogenous variables for the model. Categorical variables were treated as dummy variables and assigned values, as shown in Table 3.

The study identified that the number of hospitalization days serves as an intermediate variable, exerting both a direct and an indirect effect on hospitalization costs through other variables. Consequently, two linkage models were developed:

(1) Model 1: Multiple Linear Regression Analysis with ln Hospitalization Days as the Endogenous Variable.

The distribution of information on the dependent variable was skewed and multiple linear stepwise regression analyses were performed after logarithmic transformation to screen for number of surgeries, use of antibiotics for 17–36 days, use of antibiotics for ≥37 days and debridement surgeries, with an adjusted $R^2 = 0.208$, As shown in Table 4.

(2) Model 2: Multiple Linear Regression Analysis with lnSSI Direct Economic Loss as the Endogenous Variable.

Similarly, the distribution of the dependent variable information was skewed and multiple linear stepwise regression analyses were performed after logarithmic transformation to screen for the number of hospitalization days, age, number of days of mechanical ventilation, and use of urinary catheter for 10–36 days. Adjusted $R^2 = 0.259$. As shown in Table 5.

The recursive system model was fitted as follows:

$$Y_1 = \ln(\text{days of differential hospitalization}) = 1.705 + 0.310^{*}X_6 + 0.476^{*}X_7 + 0.567^{*}X_{14} + 1.300^{*}X_{15} + E_1.$$

$$Y_2 = \ln(\text{SSI direct economic losses}) = 7.553 + 0.373^{*}Y_1 + 0.017^{*}X_1 + 0.086^{*}X_{10} + 1.300^{*}X_{18} + E_2.$$

TABLE 3 Assignments of the variables.

Variable code	Variant	Dummy variable	Assign a value to something
Y_1	ln days of hospitalization		No
Y_2	lnSSI direct economic losses		No
X_1	Age		No
X_2	Diabetes mellitus		0 = No 1 = Yes
X_3	High blood pressure		0 = No 1 = Yes
X_4	Coronary heart disease		0 = No 1 = Yes
X_5	Lung Diseases		0 = No 1 = Yes
X_6	Number of operations		Not have
X_7	Debridement		0 = No 1 = Yes
X_8	A culture of pathogenic bacteria		0 = No 1 = Yes
X_9	Days of surgical incision drainage		Not have
X_{10}	Days of mechanical ventilation		Not have
X_{11}	Days of central venous catheterization		Not have
X_{12}	Number of days on antibiotics	≤6 days	0 = ≤6 days
X_{13}		7–16 days	0 = Other X_{13} = Yes
X_{14}		17–36 days	0 = Other X_{14} = Yes
X_{15}		≥37 days	0 = Other X_{15} = Yes
X_{16}	Number of days on urinary catheter	≤5 days	0 = ≤5 days
X_{17}		6–9 days	0 = Other X_{17} = Yes
X_{18}		10–36 days	0 = Other X_{18} = Yes

3.5 A pathway analysis of the direct economic losses due to surgical site infections and a calculation of the direct and indirect effects

Figure 3 illustrates a good model fit, indicated by Chi-sq = 7.100, df = 7, Chi-sq/df = 1.014, RMSEA = 0.009, GFI = 0.990, AGFI = 0.939, NFI = 0.969, and NNFI = 0.997. The number of surgeries, use of antibiotics for 17–36 days, debridement surgeries, and use of antibiotics for ≥37 days indirectly contributed to the number of hospital days for surgical SSI. Days of hospitalization, 10–36 days of urinary catheter use, days of ventilator use, and age directly contributed to the direct economic loss of patients with surgical SSI. As shown in Table 6, the total effect values of the factors, in descending order, were days of hospitalization, days of urinary catheter use, days of ventilator use, age, number of surgeries, use of antibiotics, and debridement surgeries.

TABLE 4 Multiple linear regression analysis of factors affecting prolonged hospitalization days in patients with SSIs.

Model 1	Unstandardized coefficient		Standardized coefficient	t	*p*	95% CI	
	B	Std	β			Lower Limit	Limit
(Constant)	1.705	0.143		11.929	0.000	1.422	1.987
Number of surgeries	0.310	0.084	0.267	3.703	0.000	0.145	0.476
Debridement	0.476	0.179	0.194	2.656	0.009	0.122	0.830
Antibiotics 17–36 days	0.567	0.178	0.227	3.191	0.002	0.216	0.917
Antibiotics ≥37 days	1.300	0.562	0.163	2.314	0.022	0.190	2.409

TABLE 5 Multiple linear regression analysis of factors affecting direct economic losses from SSIs.

Model 2	Unstandardized coefficient		Standardized coefficient	t	*p*	95% CI	
	B	Std	β			Lower Limit	Limit
(Constant)	7.553	0.427		17.679	0.000	6.709	8.397
Hospital days	0.373	0.093	0.275	4.010	0.000	0.189	0.557
Age	0.017	0.006	0.181	2.660	0.009	0.004	0.030
Days on ventilator	0.086	0.027	0.220	3.178	0.002	0.033	0.140
Urinary catheter for 10–36 days	1.300	0.348	0.259	3.740	0.000	0.613	1.986

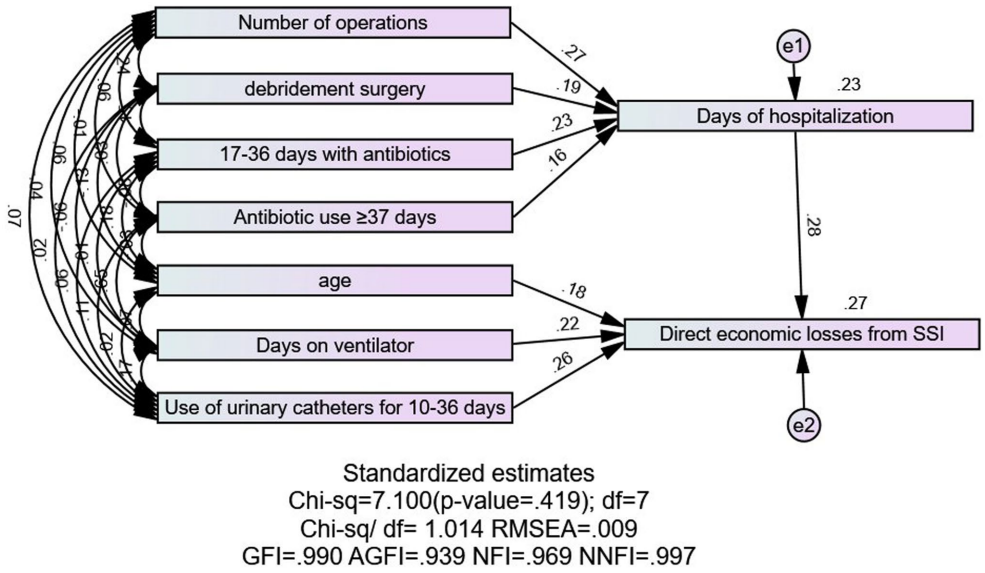


FIGURE 3
Path analysis of direct economic losses from surgical site infections.

TABLE 6 Contribution to the impact of direct economic losses of patients with SSIs by variable.

Exogenous variable	Dummy variable	Variable Code	Direct contribution	Indirect contribution	Total contribution	Ranking of total contributions
Hospital days		Y_1	0.276	0	0.276	1
Number of surgeries		X_6	0.000	0.074	0.074	5
Debridement		X_8	0.000	0.054	0.054	7
Antibiotic use	Antibiotics 17–36 days	X_{14}	0.000	0.063	0.063	6
	Antibiotics ≥37 days	X_{15}	0.000	0.045	0.045	8
Age		X_1	0.182	0	0.182	4
Days on ventilator		X_{13}	0.221	0	0.221	3
Use of urinary catheters	Catheter 10–36 days	X_{18}	0.260	0	0.260	2

4 Discussion

The occurrence of SSIs can lead to unplanned readmissions, debridement procedures, prolonged hospital stays, and delays in resuming normal work activities, incurring financial losses for patients (5). Despite interventions before and after surgery, the incidence of SSIs remains high, with an estimated 16,049 deaths annually (18). Critically, assessing and comparing the direct economic losses from SSIs with those from other diseases is essential for more focused attention and policy development. This study employed a case–control approach to analyze the direct economic losses from SSIs in surgical patients, assess both direct and indirect contributions of influencing factors using recursive system modeling, and calculate the overall public impact. Thus, understanding the factors influencing hospitalization costs for SSI patients is crucial for cost management and provides valuable insights for medical departments to implement strategies that reduce SSI rates and enhance patient safety.

The study revealed that the direct economic loss for SSI patients averaged $1,364.37. The median hospitalization cost was $6,623.97 for the case group versus $4,814.30 for the control group, significantly higher in the case group. The total direct economic loss for SSI patients in the three hospitals was $467,867, with medications accounting for the highest proportion at 24.26%. A systematic review involving 15 low- and middle-income countries and 16 European countries (19) found that economic losses from SSIs ranged from $174 to $29,610 in low- and middle-income countries, and from $21 to $34,000 in European countries. A French cohort study (10) reported the average cost of SSI treatment as approximately €1,814. Further, a study in China (20) noted that the direct economic loss from SSI in liver surgery patients was $5,408.20, with the highest proportion of costs attributed to medications, aligning with this study's findings. The increased medical cost for SSI patients in a tertiary hospital in China was reported as $14,160.30 (21). Reasons for these variations include differences in study data, regional disparities in diagnostic and treatment capabilities, and the specific nature of the patient's condition affecting treatment costs.

In the recursive system model analysis, the number of surgeries, debridement procedures, and antibiotic use were found to directly affect the number of hospital days and indirectly affect hospitalization costs. Studies have indicated (14, 22) that the number of surgeries directly impacts hospital stay lengths and indirectly influences hospitalization costs, aligning with this study's findings. On one hand, multiple surgeries during hospitalization can lead to increased blood loss and surgical incisions, reducing immunity, slowing incision healing, and elevating infection risks, thereby extending the hospital stay. On the other hand, increased surgeries may incur additional fees for surgery, anesthesia, and postoperative care, raising hospitalization costs. Moreover, if a patient develops an SSI, it may necessitate readmission or debridement surgery, directly prolonging the hospital stay and indirectly escalating the patient's financial losses.

Studies have demonstrated that using antibiotics for 17–36 days and ≥ 37 days can extend hospital stays. Prolonged antibiotic use may indicate medical staff concerns about potential SSIs, leading to added pathogen cultures and extended hospital stays (23). Slow detection of pathogen cultures may delay appropriate antibiotic administration, thus delaying infection symptom recovery and prolonging hospitalization. Furthermore, prolonged antibiotic use may promote drug-resistant bacteria development, reducing antibiotic effectiveness and necessitating the use of more advanced antibiotics, which wastes treatment time and extends hospital stays, indirectly impacting patients' direct economic losses. Research shows (24) that extended postoperative antibiotic use does not decrease SSI rates. Hence, medical staff should enhance pathogenic delivery rates, improve drug sensitivity testing rates, and utilize antibiotics more judiciously to maximize therapeutic effects, shorten hospital stays, and minimize patients' direct economic losses.

Rational prophylactic use of antibiotics is a crucial strategy to prevent SSIs. A meta-analysis (25) including 48 randomized controlled trials demonstrated that prophylactic antibiotics during surgery effectively reduce the incidence of SSIs. Flores-Yelamo et al. (26) found that a bundle package—consisting of prophylactic antibiotics, mechanical bowel preparation, perioperative glucose monitoring, adequate debridement, maintenance of intraoperative body temperature, use of a 2% chlorhexidine gluconate alcohol solution for skin disinfection, and changing instruments before wound closure—significantly lowered the risk of SSIs. Therefore, to prevent and control SSIs, healthcare professionals should assess the infection risk before surgery adequately. For high-risk patients, such as those with implants, long operating times, or who are immunocompromised, the use of

appropriate prophylactic antibiotics can effectively reduce the risk of SSIs.

The study demonstrates that the number of hospitalization days serves as an intermediate variable, directly and indirectly affecting hospitalization costs. This correlation indicates that hospitalization costs increase with the length of stay. The duration of hospitalization was identified as a critical factor in the direct economic loss of SSI patients, corroborating findings from other studies (14, 22). Possible reasons include, on one hand, long-term hospitalized patients may present with more underlying diseases, complex conditions, compromised immunity, and extended physical rehabilitation needs, thereby prolonging their stay and increasing treatment and care costs. On the other hand, prolonged hospital stays heighten the risk of hospital-acquired infections, escalating antibiotic use and laboratory tests, such as cultures for pathogenic bacteria, thus directly increasing patients' economic losses.

Research indicates that extended catheter retention correlates with increased hospitalization costs, aligning with other findings (27, 28). Postoperative urinary retention occurs in 2.5 to 43% of patients (29), typically resolved by temporary catheterization. Furthermore, pre-operative catheterization, often necessitated by anesthetic effects, may lead to prolonged postoperative urinary retention, thereby raising hospitalization costs. Prolonged catheter use may also cause urinary tract infections, increasing antibiotic usage and thus contributing to direct economic losses for patients. Additionally, for bedridden patients, catheters are sometimes requested by medical staff or family to manage daily living challenges, which extends catheter use and incurs further economic losses.

Studies also reveal that the number of days on mechanical ventilation directly impacts the direct economic loss of SSI patients, with longer ventilation periods correlating with higher healthcare costs (30, 31). This increase can be attributed to several factors: the aging population has elevated the clinical use of mechanical ventilation and its associated costs. Moreover, ventilated patients often have complex and critical conditions, leading to additional bedside exams, laboratory tests, and medications, which all raise hospitalization costs. Additionally, ventilated patients, often with reduced autonomy or in comatose states, require extensive life support and basic care, such as nasal feeding and skin care, further increasing care costs.

Studies have shown that the older the patient, the more significant the direct impact on the economics of SSI. However, other studies (13, 32) suggest that age indirectly affects hospitalization costs by increasing the length of stay, which does not entirely align with the findings of this study. On one hand, as age increases, patients often suffer from chronic conditions such as hypertension, diabetes, and cardiovascular diseases, necessitating additional pre-surgery tests and adjustments to manage blood sugar levels and meet surgical requirements, thereby directly increasing healthcare costs. On the other hand, declining bodily functions, slower metabolism, and decreased immunity in older patients may delay post-operative recovery and mobilization, leading to prolonged treatment and additional costs, thus directly affecting the patient's economic losses.

4.1 Limitations

This study has several limitations. First, a retrospective design was used instead of a prospective approach, potentially underestimating the number of SSIs and limiting the ability to monitor correlations and statistical differences among certain variables. Second, the study focused on the direct economic losses from SSIs, excluding indirect losses. Additionally, these findings may not be applicable in other countries. Finally, the sample size was small. Future prospective studies with larger sample sizes are planned to further identify the key factors contributing to direct economic losses from SSIs.

5 Conclusion

The direct economic loss from SSI is substantial and influenced by various factors. The impact of each factor on the direct economic loss from SSI is ranked by contribution as follows: hospitalization days, indwelling urinary catheter days, ventilator days, age, number of surgeries, antibiotic use, and debridement surgeries. Therefore, hospitalization days are identified as the primary contributor to the direct economic loss from SSI. In clinical practice, efforts should be made to shorten hospital stays according to the patient's condition, use urinary catheters judiciously and remove them as soon as feasible, and for surgical patients, medical staff should limit staged surgeries, use antibiotics judiciously, and focus on SSI prevention. By controlling modifiable factors, the incidence of SSI can be reduced, thus diminishing the direct economic losses to patients and providing a theoretical foundation for relevant departments to implement preventive and control measures against SSI.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: the data of this study are available from the corresponding author upon request. Requests to access these datasets should be directed to Qiuxia Zuo, zz1109431009@163.com.

Ethics statement

The studies involving humans were approved by the Ethics Committee of the Fifth Affiliated Hospital of Xinjiang Medical University. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

QZ: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Visualization, Writing – original draft, Writing – review & editing. DL: Data curation, Formal analysis, Investigation, Project administration, Resources, Software, Writing – original draft, Writing – review & editing. BD: Investigation, Resources, Supervision, Writing – review & editing. YZ: Methodology, Project administration, Resources, Writing – review & editing. KZ: Formal analysis, Methodology, Writing – original draft,

Writing – review & editing. PT: Conceptualization, Data curation, Formal analysis, Funding acquisition, Resources, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The author(s) declare that no Gen AI was used in the creation of this manuscript.

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Implementation and performance barriers in Iran's breast cancer screening program: a qualitative case study

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Introduction: Cancer screening programs (CSPs) are essential for early detection and improving survival rates; however, they often encounter barriers to effective implementation. This study aims to identify the key challenges faced in implementing the Breast Cancer Screening Program (BCSP) in Iran, with the goal of providing insights to enhance the program's effectiveness and accessibility.

Methods: This study was conducted as an observational and qualitative research to assess the implementation status and identify barriers within the Breast Cancer Screening Program (BCSP). Data were collected through a combination of interviews, process observations, and document reviews. A purposive sample of 37 participants was interviewed, including individuals involved in the management, implementation, or evaluation of the screening program. Thematic content analysis was employed to analyze the data, with saturation achieved to ensure comprehensive coverage of the study's objectives.

Results: The study identified several key barriers to the effective implementation of breast cancer screening programs, which were categorized into three main dimensions: infrastructural, managerial, and healthcare service delivery. The most critical issues in infrastructural category were a lack of trained healthcare personnel, insufficient screening facilities, inaccurate registration systems, fragmented databases, and poor data quality control. Key barriers in the managerial dimension include the absence of a mechanism for identifying and inviting women eligible for cancer screening, as well as inadequate monitoring of non-responders to follow-up. Overcrowding during peak times, long waiting periods, inaccurate triage, and lack of general practitioners (GPs) at the primary level of public healthcare were the identified barriers in service delivery in cancer screening. Additionally, interviews with women revealed several barriers, such as low perceived risk, fear and anxiety, lack of family support, and cultural or religious objections, all of which further hindered participation in breast cancer screening.

Conclusion: This study highlights the critical barriers to the implementation of breast cancer screening programs in Iran, most of which appear to stem from systemic failures. Addressing these challenges requires a comprehensive, strategic approach that targets the identified obstacles at multiple levels. Overcoming these barriers is crucial to improving the accessibility, efficiency,

and overall effectiveness of breast cancer screening programs, ultimately enhancing early detection and patient outcomes.

KEYWORDS

barriers, health system and services, cancer screening program, breast cancer, qualitative

Introduction

Among women, breast cancer accounted for approximately 24.5% of all cancer cases and 15.5% of cancer deaths, ranking first for incidence and mortality in the majority of the world countries in 2020. Breast cancer is one of the most prevalent types of cancer in Iran and are expected to remain the leading cancer nationally in 2025 (1). Estimates in Iran show from 2016, the trend of breast cancer has been increasing and this growth is expected to continue until 2040 when the number of cancers will more than double compared to 2020 (1). Based on a literature, the prevalence of breast cancer in Iranian women was 34.5 per 100,000 (2, 3).

Based on the evidence, early detection of cancer plays a pivotal role in future therapeutic methods and significantly improves the chances of successful treatment (4). Romero et al., reported that that there were fewer breast cancer early detection programs in Low and Middle Income Countries (LMICs) compared with high-income countries (5). Then, late-stage breast cancer diagnoses are more common in low- and middle-income countries (LMICs). Evidence shows that in high-income countries (HICs), 70% of breast cancer cases are diagnosed at stages I or II, whereas in LMICs, fewer than 50% of patients are diagnosed at these early stages (6).

Screening is an essential step in the early diagnosis of diseases that can detect breast cancer before it has any symptoms (7). Population-based screening programs can be personalized, categorizing women into different groups based on individual risk factors and preferences (8). One of the goals of implementing organized breast cancer screening programs is to achieve high participation rates among the target population and maintain consistent follow-up in breast cancer screening (9). Like most of developed and developing countries (10, 11), Iran's National Cancer Control program (IRCCP) was developed comprehensively in 2013 with cross-sectoral cooperation and stakeholder participation. Early detection of breast cancer is one of the targets within this program (12).

Despite substantial advances in the early diagnosis and treatment of breast cancer, it remains one of the leading causes of cancer-related mortality among women (13). Several methods are recommended for breast cancer screening, including digital mammography, digital breast tomosynthesis, breast ultrasonography, magnetic resonance imaging (MRI), and clinical breast examination (CBE) (14). Currently, mammography is regarded as an effective screening method for detecting breast cancer at its early stages (15). Based on the results of a study in Iran, more than half of the participants underwent breast self-examination (BSE), clinical breast examination (CBE), and mammography at least once. However, only a small percentage performed these examinations regularly and in accordance with recommended guidelines. Specifically, 9.9% conducted BSE regularly once per month, 8.9% underwent CBE regularly twice per year, 12.3% had mammography regularly once per year, and 3.8% received sonography regularly twice per year (16). Another study is reported the BSE, CBE and mammography rates were 4.1, 5.6 and 4.8%, respectively (17). These rates fall short of the established targets when compared to those in other countries (18, 19).

Based on literature, well organized cancer plans that are linked to strong governance mechanisms improve cancer outcomes. However, many of these plans are not being implemented because of underfunding, inadequate expertise for scale-up, competing priorities, or lack of political will. Based on the WHO report from 2015, about one in four countries do not operationalize their National Cancer Control Plan (NCCP) or Non-Communicable Disease (NCD) plan (5, 10). Therefore, in light the importance of implementing a breast cancer screening program for early detection and timely treatment, it is crucial to evaluate the program to identify any underlying challenges. This research aims to identify systemic obstacles by evaluating breast cancer screening through interviews with both healthcare providers and women.

Materials and methods

This research was carried out in two phases: an observational study to extract the workflow of the breast cancer screening program, and a qualitative study to identify the challenges of the program from the perspectives of both health service providers and women.

Extraction of the breast cancer screening workflow

To ensure a comprehensive understanding and enhance the reliability and validity of the findings, we employed a triangulation approach by integrating three data collection methods: interviews, direct observations, and document analysis.

- Interviews: 11 healthcare providers directly involved in the screening process were interviewed. The purpose of these interviews was to gain detailed insights into the routine workflow, including the sequence of tasks, roles of different staff members, and standard procedures followed during screening. The interviews helped to map out the step-by-step process and

Abbreviations: NCI, national cancer institute; LMICs, low- and middle-income countries; CSP, cancer screening program; BCSP, breast cancer screening program; HRH, human resources for health; MRI, magnetic resonance imaging; CBE, clinical breast examination; HICs, high-income countries; CHS, comprehensive health service; EDC, early detection cancer; BCS, breast cancer screening; CHCC, comprehensive health care center; BSE, breast self-examination; MOHME, Ministry of Health and Medical Education; PCPs, primary care physicians; HIS, Health Information Systems; HIT, Health Information Technology; GPs, general practitioners.

identify any variations across different healthcare centers. The participants included midwives ($n = 2$), healthcare workers ($n = 3$), physicians at health service centers ($n = 2$), executive directors of health service centers ($n = 2$), and staff from the Deputy of public health, including the heads of the non-Communicable diseases group ($n = 1$) and the family health group ($n = 1$).

- Process Observation: The researchers (A.J., S.L.) observed the workflow at four Comprehensive Health Service (CHS) centers and one Early Detection Cancer (EDC) center. These observations focused on key operational processes, including patient admission, patient flow, staff interactions, information registration in databases, screening procedures, and the use of medical records, diagnostic tools, and patient discharge. The researcher systematically documented the steps involved in the cancer screening program. Observations were conducted during regular working hours over multiple days to capture routine practices and potential challenges in implementing screening protocols. After identifying the various components of the workflow and reaching saturation of results without discovering new steps, the researcher developed a framework for implementing the screening program.
- Document analysis: A comprehensive review of the relevant documents was also undertaken, including national guidelines related to breast cancer screening, to assess their alignment with current practices in the field (See details in Supplementary 1).

Qualitative phase

Following the extraction of the workflow of the BCS program, the researchers evaluated the process for potential challenges through face-to-face interviews.

The study sample is categorized in two parts health care providers and women. In this study, purposeful sampling was employed to select health providers with specific knowledge, or expertise relevant to screening programs.

- In the first group, we interviewed with involved staff in providing breast cancer screening services including midwives, nurses, physicians, executive directors, and managers from the public health deputy (such as the director of the non-communicable diseases department, the family health group, and staff responsible for the registration and monitoring of the program's implementation and referrals for screening and breast cancer patients). The inclusion criteria for health providers specified that individuals must have at least 3 years of executive or supervisory experience in breast cancer screening.
- In the second group, we used convenience sampling method. The inclusion criteria for the participants were as follows: women aged 30 years and older, with no previous or current diagnosis of breast cancer, and women who did participate during the screening process at the first or the second-level health centers.

Interviews were conducted until data saturation was achieved. Saturation was reached after we thoroughly explored all the interview questions, and no new themes emerged during subsequent interviews with participants, resulting in a total of 37 participants (14 health providers and 23 women). It is noteworthy to mention, 11 participants from Phase 1, who were interviewed to identify the steps of breast cancer screening program, also participated in phase 2, where the challenges in the program were explored.

The interview questions were designed as open-ended and based on a thorough review of relevant studies. To effectively capture the challenges associated with implementing the breast cancer screening program, the questions were divided into two categories: existing challenges from the perspectives of healthcare professionals and women.

- Healthcare professionals' perspective: The questions addressed the perspectives of the healthcare providers across six domains—human resources, information management, technology, governance and leadership, financial aspects, and drugs and equipment—and included a total of 20 questions (See details in Supplementary 2).
- Women perspective: We explored women's knowledge and attitudes due to seven questions toward breast cancer risk factors, their previous experiences with mammography and clinical breast examinations, and recommendations for mammography frequency across various age groups and risk level. We also examined their concerns about current screening practices and the factors influencing their decisions to either undergo or forgo mammograms and clinical breast examinations. Additionally, we investigated the role of social support and communication with healthcare professionals and family, as well as barriers and facilitators related to access, cost, and physical issues within the screening program system (See details in Supplementary 2).

Conduct interviews and data collection

Each interview lasted approximately of 30–35 min. At the beginning of each interview, the purpose of the study was explained, consent to record the interview was obtained, and participants were assured of the confidentiality of the content, including the anonymization of any examples used. Data collection continued until 70% saturation was reached, meaning no new information was emerging from subsequent interviews. Following the interviews, key components relevant to the study objectives were identified and categorized. Two researchers (Z.N. and A.J.) then organized these components into themes, categories, and subcategories. The classifications were compared, and any discrepancies were resolved through discussion. In cases of disagreement, a third party's opinion was sought, leading to a final consensus. Participant quotations corresponding to each main theme were subsequently compiled and presented for clarity and reference.

Data validation

Four criteria including credibility, confirmability, transferability, and dependability were used to maintain the trustworthiness of the extracted themes. Credibility was boosted through prolonged engagement with interviewees, the achievement of data saturation, and the sampling method. Also, member check supported credibility. After data analysis, participants were provided a complete transcript

of their coded interviews. They confirmed the extracted themes. Meanwhile, maximum variant sampling (different positions, backgrounds) also validated the confirmability of data. In the case of reliability of study results, we asked other researchers in the field to assess the coding process. They were two experts who were experienced in qualitative research. They checked the transcripts of interviews and coded them as well. Then reliability of the coding was calculated to the number of agreed codes over the total number of codes for Inter-Rater Reliability (IRR). A score of more than 70% is considered a desired agreement. Additionally, the results were discussed with two people—experts in the field of non-communicable disease- who did not participate in our interview but who confirmed the soundness, fitness and transferability of the results. This confirmed transferability of results.

Data analysis

Thematic content analysis was employed to analyze the data obtained from interviews, which were presented in textual form. The primary tool used in content analysis is the categorization system, in which each textual unit is coded and assigned to one or more categories. Each category was defined to be clear, comprehensive, and relevant, with the aim of capturing the text's meanings as fully as possible while avoiding generalization and ensuring completeness. The analysis of the interviews utilized a comprehensive (inductive) approach, focusing on the criteria of the screening program. Two members of the research team independently reviewed the interviews. The results were found to be over 90% consistent.

Results

A total of 37 participants took part in the study. To identify the steps involved in breast cancer screening, 11 healthcare providers were interviewed. In order to explore challenges in the breast cancer screening program, 14 healthcare providers and 23 women were interviewed. The characteristics of the interviewees are detailed in Table 1. Most interviewees were aged between 40 and 49 years (40.5%). Among the women, 39% had a primary education level, while 27% of healthcare professionals held a bachelor's degree, and 50% of them had over 10 years of work experience.

TABLE 1 Participants characteristics (n = 37).

	Health care providers	Women
Age, years, mean ± SD	44.28 (10.43)	44.13 (6.33)
Education level		
No-formal education	0	6
Elementary school	0	3
Middle and high School	0	2
Diploma	0	10
College level	14	2
Work History		
5<	3	22
5-10	4	1
>10	7	0

Breast cancer screening steps in Iran

The process of breast cancer screening (BCS) program is extracted from interviews within the primary and secondary levels of the health care system in Iran, begins with women attending a comprehensive health care center (CHCC) for a clinical breast examination. It is important to note that the target population is not actively recruited into the BCS program. Then, participants were women who were either highly motivated to engage in screening or who sought other healthcare services at the CHCC. Following this, midwives assessed these women using a structured questionnaire to determine their risk levels and subsequently conducted physical examinations to identify any abnormal breast masses.

During this process, women are educated on breast self-examination (BSE) for at-home use. For women with normal breast tissue aged between 30 and 40, a follow-up period of 2 years is recommended, whereas women older than 40 are advised to have follow-ups annually. Midwives refer patients who are identified as high-risk based on their medical history or those with abnormal clinical breast examinations to an EDC center at the secondary care level.

Following a positive result from breast screening sonography or mammograms indicating malignancy, patients are referred for breast tissue sampling (needle biopsy) or additional imaging to determine the stage and grade of the cancer. Meanwhile, for women with negative mammograms, annual sonography is recommended for those aged between 25 and 30, and annual mammography is recommended for those aged 30 and older (see Figure 1).

Challenges in the breast cancer screening program

The identified challenges in the breast cancer screening program are categorized into three main dimensions: (a) infrastructural barriers, (b) managerial-related barriers, and (c) healthcare service delivery barriers (Refer to Conceptual Framework in Supplementary 3).

(a) Infrastructural Barriers: The findings indicate that the infrastructural dimension encompasses four key themes: human resources for health (HRH), physical infrastructure, health information systems, and medical facilities.

The main categories in the HRH were related to the quantity and quality of personnel. Identified barriers include restricted access to screening due to a shortage of skilled providers knowledgeable about screening guidelines and the high workload of primary care providers (such as midwives and general practitioners). Additional challenges include an insufficient number of specialist physicians at the secondary care level and a lack of motivation among healthcare providers due to inadequate compensation (see Table 2).

The findings reveal several concerns related to physical infrastructure, including the presence of only one EDC center at

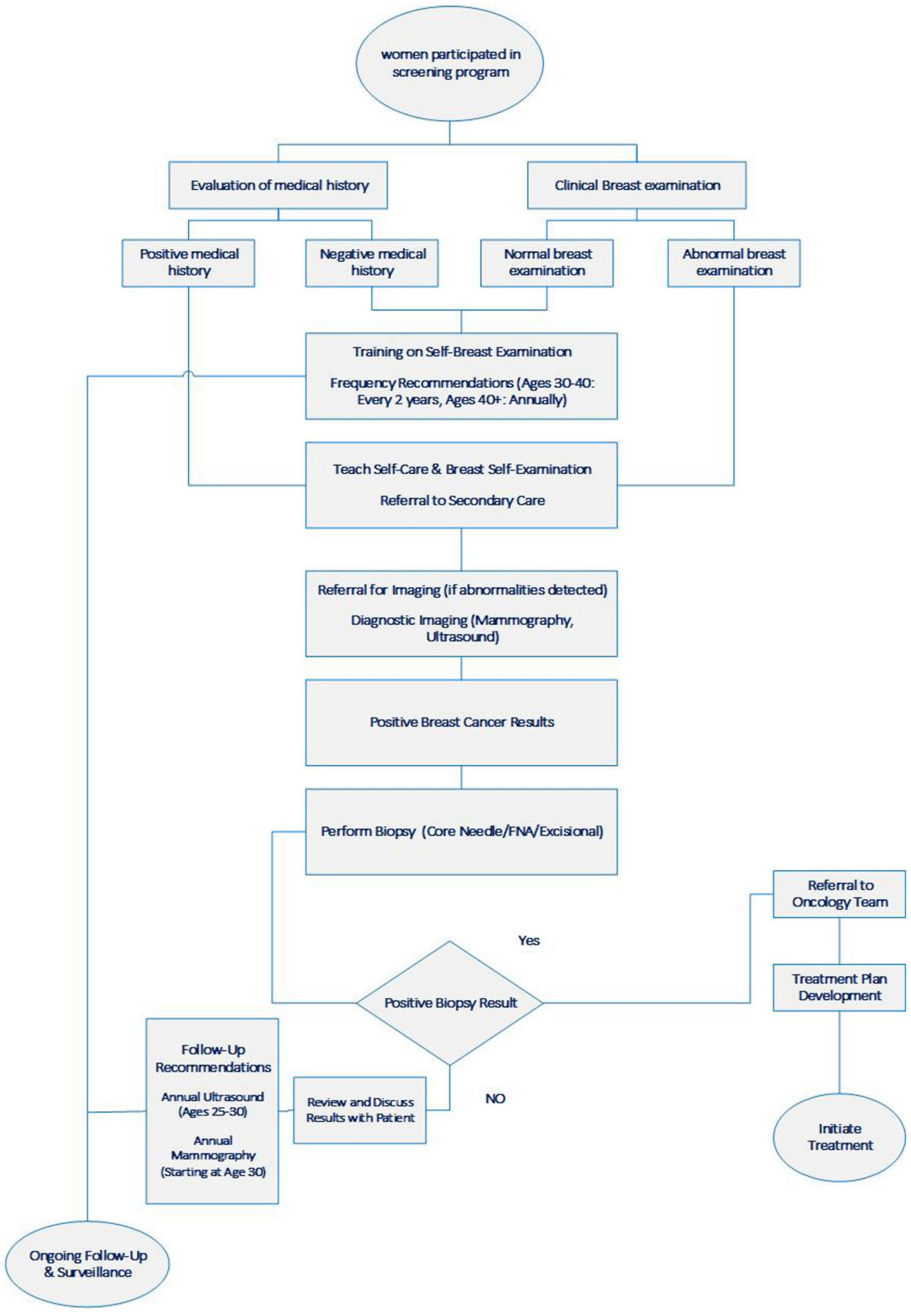


FIGURE 1
Breast cancer screening steps in Iran.

the secondary care level, the absence of changing rooms in primary care centers, and the lack of dedicated screening rooms for breast examinations. Additionally, there is a shortage of EDC centers in other cities and transportation barriers to accessing the early detection cancer center due to geographic location (see Table 2).

The health information system is crucial at the primary care level. The integrated health record system, known as "SIB," is the predominant information system used for recording public health data in Iran. All health-related data within primary health services are recorded in the SIB. However, participants identified several weaknesses related to the SIB, including inaccuracies and incompleteness in the population register, time-consuming risk evaluation using the breast cancer risk assessment tool, and a lack of linkage between the SIB and other databases (governmental, private, and cancer registry). Additional issues include the absence of electronic health records at the screening level (EDC center), an inadequate referral system between different levels of care, no online booking system, failure to record screening results in the relevant database, lack of data quality control mechanisms, and insufficient information sharing or promotion of screening among providers across different levels (see Table 2).

TABLE 2 Infrastructural barriers.

Theme	Category	Subcategory	Quotes
Human Resources for Health (HRH)	Quantity	• Insufficient number of specialist physicians at the secondary care level	"Many of centers do not have doctors, especially in our urban areas." "The early detection cancer center depends a lot on specialist doctors. If one decides to leave, we cannot find a replacement like her."
		• Lack of general practitioners in comprehensive health service centers in the primary care level	
		• Inadequate number of skilled providers knowledgeable about screening guidelines	
		• Shortage of midwives and healthcare workers in comprehensive health service centers in the primary care level	
	Quality	Lack of motivation among healthcare providers due to insufficient payment	"It does not make sense to have specialists at the early diagnosis center since I do not get paid the same way other specialists in hospitals."
		Instability in the workforce and the use of the temporary staff	
		Weaknesses in continuing education programs	
		Screening tasks are often deprioritized due to the high workload of healthcare workers	
Physical Infrastructure	Facilities	• Lack of suitable screening rooms for breast examinations	"I do not think this location for breast exams is ideal. We do not have a proper room to ask about medical history, educate women, or do the breast assessments.
		• Limited number of early cancer detection centers in the province (only one center)	
		• Inappropriate locations of comprehensive centers in cities	
		• Weaknesses in welfare facilities at comprehensive health and early detection cancer centers	
Health Information System	Databases Linkage	• Lack of linkage between SIB and other databases (governmental, private, and cancer registry)	"The SIB database is pretty good and has everything we need, but the issue is it's not connected to the main screening center in the province. So, we cannot really follow up on suspicious cases effectively."
		• Absence of electronic health records at the early detection cancer center	
		• Outdated information in the province's cancer registration system	
		• Limited access to screened patients' information across different sectors	
	SIB Weaknesses	• Inadequate referral system between care levels	"The SIB system works for primary care, but it does not connect with the secondary level. So, when a midwife assesses a patient and refers them to the secondary level, we cannot follow up because there's no connection. Since we do not have any other way to follow up, we end up using social media like WhatsApp to keep track of our patients who are referred to the second level
		• Lack of an online booking system	
		• Lack of recording the screening results	
		• Inability to register foreign patients who living in Iran in the SIB database	
		• Lack of sharing screening information between providers at different levels	
		• Absence of a data quality control mechanism	
		• A time-consuming process to determine the level of cancer risk	
		• Lack of an active queue system between health care levels	
		• Delays in updating statistics in the SIB system	
		• Lack of an integrated follow-up mechanism for suspected patients	
		• Limited access to all necessary data in the SIB database	
Medical Facility	Medical Facility	• Failure to use appropriate devices to protect patient privacy in comprehensive health centers	"In terms of medical equipment's, we mostly go to the midwife's room for examinations, because there is no place to examine breast."
		• Lack of replacement equipment in the early diagnosis center	

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Mammography and sonography are the only medical facilities utilized at the primary and secondary care levels. The primary challenges in medical facility category include a limited number of these facilities, which contributes to high workloads and a lack of substitutes for medical equipment in case of breakdowns. Additional issues involve inadequate maintenance of the facilities and deficiencies in user proficiency (see Table 2).

(b) Managerial barriers: Our findings indicate that the health system's oversight of the national breast cancer screening program is inadequate. Although specialized national committees within the Ministry of Health and Medical Education (MOHME) have developed and disseminated guidelines and protocols for breast cancer screening to the provinces, there is a lack of active supervision to ensure compliance with these guidelines and assess provincial performance.

Main barriers in this dimension include the absence of a well-defined mechanism for identifying individuals eligible for screening, insufficient processes for individually inviting women to participate in cancer screening, and inadequate systems for referring screen-positive cases and reporting screen-negative results. Additionally, there is insufficient monitoring of non-responders to follow-up, a lack of an integrated education program, resource constraints, and a disconnect between primary and secondary care levels in the screening pathway. Other issues include the admission of patients from external referral systems based on self-referral without prior invitation from healthcare providers, the absence of a monitoring and evaluation mechanism for the cancer screening program's performance, and a lack of a clear plan to enhance population participation (see Table 3).

(c) Service delivery barriers: At the primary healthcare level, comprehensive health care centers serve as the initial point of contact for preventive medicine. After identifying high-risk women, these centers refer them to an EDC center for further evaluation. The findings indicate that public access to cancer screening services was enhanced by the introduction of EDC centers at the secondary healthcare level. Additionally, due to cultural and religious considerations, all clinical breast examinations at the primary care level are conducted by female staff.

However, there are several barriers in health service delivery. The first category pertains to the healthcare system. Participants identified several issues adversely affecting access to the screening program, including the use of the same healthcare providers for multiple services in the public health sector (e.g., immunization and maternal care), the absence of a queue management system, overcrowding during peak times, long waiting periods for appointments, restricted availability to clinics, inadequate follow-up of test results, inaccurate clinical breast examinations performed by midwives, and the practice of referring patients to secondary care (mammography) without proper triage. Additionally, the lack of visits by primary care physicians (PCPs) before referral to secondary care and the challenge of scheduling screenings, particularly for employed women due to the centers' morning hours, further complicate access to the screening program.

According to the women interviews' results, barriers preventing women from participating in the cancer screening program include a lack of knowledge about screening, cultural and religious objections to mammography and clinical breast examinations, and fear and anxiety related to cancer and screening outcomes (such as cancer diagnosis, pain during the procedure, and false positive results). Other challenges involve inadequate financial coverage for tests in the private sector, inability to afford indirect costs associated with screening such as transportation, resistance to undergoing mammography due to a lack of symptoms and a perceived sense of good health, ineffective communication between doctors and patients, and mistrust of public versus private healthcare facilities. Additional barriers include lower motivation for annual screening, discomfort with disrobing for the examination, busy schedules, negligence regarding health, and insufficient family support (particularly from spouses). The findings also indicate that women have limited knowledge about risk factors, symptoms, screening frequency, and the appropriate age for breast cancer screening. Therefore, there is a need to enhance patient education regarding the importance of breast self-examination (BSE) and available screening options (see Table 4).

Discussion

This qualitative study aims to identify the challenges associated with implementing breast cancer screening programs. Through interviews with healthcare professionals and women, the identified challenges are categorized into three primary dimensions: infrastructural, managerial, and healthcare service delivery barriers.

There is limited evidence for the efficacy of CBE as a population-based screening modality in Iran, where mammography is not routinely performed. Although mammogram machines are expensive, and their only application is in breast imaging, limiting their accessibility in only in one center in the governmental health sector in Iran. Literature suggests that CBE as part of comprehensive breast health awareness may have value in improving the opportunities for early diagnosis of a (potential) future breast cancer (20, 21).

Based on our finding, several infrastructure-related barriers affect the effectiveness of cancer screening programs. These include a shortage of personnel, insufficient number of EDC centers; inadequate facilities within health centers; and a limited availability of mammography and sonography units. Our results are supported by other studies. For instance, Prisca et al. highlight staffing shortages and inadequate on-the-job training in midwifery services for breast cancer screening as barriers to the integration of clinical breast examinations (CBEs) with cervical cancer screening (CCS) services in primary care clinics (22). Similarly, Mosquera et al. found that there is a lack of professionals adequately trained in screening protocols and guidelines (23).

Limited human resources for breast and cervical cancer screening became factor that influenced the ability of the programs to meet their targets. Then, the availability of these resources is contingent upon the education system's capacity to produce diverse cadres of healthcare providers and the health system's ability to attract, motivate, and retain them (24).

Offering appropriate diagnostic and treatment services involves ensuring access, which is determined by the available infrastructure and workforce. Some programs have used mobile units to improve access to screening and diagnosis. However, evidence of the effectiveness of these interventions is currently limited (25, 26).

Health Information Systems (HIS) in cancer screening program faced several critical challenges. First, the target population is not accurately registered for identification, invitation, and follow-up related to screening in the HIS. Additionally, the presence of disparate and non-integrated databases across different healthcare levels

TABLE 3 Managerial barriers.

Theme	Category	Subcategory	Quotes
Managerial barriers	Planning	• Unclear organizational structure of early detection cancer centers within the health system	"The early detection center is located in a public hospital, and patients must pay for screening services at the hospital cashier. However, the hospital manager claims that the center is not part of the hospital but is instead governed by the Primary Health Care (Health Deputy). As a result, we do not receive any budget allocation from the hospital, leading to significant weaknesses in our required equipment."
		• Defects in human resource planning specific to the screening program	
		• Failure to establish an integrated system at both primary and secondary care levels	
		• Admission of patients from other areas (self-referrals and screenings without invitation or provider advice)	
		• Lack of awareness among healthcare providers regarding national protocols and guidelines	
		• Absence of an integrated education program	
		• A high level of hierarchy within centers	
	Performance monitoring and evaluation	• Lack of a monitoring and evaluation mechanism for CSP performance	"I had a biopsy at the doctor's office, and it cost me 2 M. The mammography and ultrasound were also really expensive in the private sector."
		• Absence of an evaluation and accreditation system for health, particularly in screening programs	
		• No specific program to monitor and report statistics as requested by higher authorities	
		• Conflict of interest, such as referring patients to private sector	
	Resourcing	• Lack of prioritization in funding for equipment purchases and resource allocation for physical space development	"One reason for the shortage of staff in public health is that screening services are not profitable. As a result, specialists are reluctant to work in this area due to low payment"
		• Absence of performance-based incentive programs for comprehensive health centers	
		• Costs not being fully covered (e.g., payment required at the secondary care level, leading to reluctance among some patients to follow up)	
		• Insufficient financial incentives for specialists in early detection centers	
		• Resource constraints	
	Mechanisms	• No well-defined mechanism for identifying the population eligible for screening	"Midwives have to prioritize their work. So, if a pregnant woman comes in for prenatal care, she gets priority over someone coming in for another reason."
		• Insufficient mechanism for individually inviting women to cancer screening	
		• Inadequate referral mechanism for screen-positive patients and reporting of screen-negative results	
		• Failure to define a patient tracking system (target population, suspected cases, and confirmed cases)	
		• System defects in some reports requested by higher authorities, requiring manual entry in Excel format	
		• Lack of a prioritization system between screening clients and other clients (e.g., vaccinations and prenatal care, due to shared staff)	
	Community participation	• Absence of a coherent public education program (relying on opportunistic and passive education methods)	"We have a Week Against Cancer where we inform the public and hold training sessions in various locations."

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TABLE 4 Service delivery barriers.

Theme	Category	Subcategory	Quotes
Service Delivery Barriers	Availability	Using shared health providers for different services in the public health sector (e.g., immunization, maternal care and also screening)	"This center has only one specialist." "Our peak time is from nine to eleven in the morning, so all services should be available during those two hours."
		Unclear schedule for physician availability and center closure in the absence of a doctor	
		Irregular attendance of personnel at the workplace due to the doctor's absence	
		Absence of an appointment system	
		Congestion during morning hours at comprehensive health centers	
		Difficulty in allocating time for screening, especially for employed women, due to the centers' morning hours	
		Long waiting times for appointments	
		Limited availability of doctor visits in early diagnosis centers	
		Failure to protect patient privacy during examinations, lack of patient comfort	
		Failure to follow up patients referred from first to second and from second to third levels	
		Long distances to the early cancer diagnosis center within the province and high transportation costs, especially for patients coming from other cities	
		Lack of financial coverage for diagnosis tests in secondary care	
		Inappropriate and small waiting room space for patients	
		Limited operating hours of the early diagnosis center (one day a week)	
		Absence of a separate cashier for covering expenses at the early diagnosis center, requiring patients to rely on the public hospital cashier	
		Long and inefficient process for receiving mammography and ultrasound results	
	Patient attitude	Lack of knowledge about screening	"I think the sonography at the public center wasn't very accurate. They identified something suspicious but did not explain it clearly. I went to the private sector for a more accurate assessment."
		• Cultural barriers to mammography and clinical breast exams	
		• Fear and anxiety about cancer and screening outcomes (e.g., cancer diagnosis, pain during the procedure, false positive results)	
		• Resistance to undergoing mammography due to the absence of symptoms and a perception of being healthy	
		• Lower intention to participate in annual screening	
		• Discomfort with removing clothing during the screening process	
		• Unpleasantness of the mammography process	
		• Distrust of public healthcare facilities compared to private sector options	
	Acknowledgment and acceptance of the patient	• Lack of awareness among patients about symptoms, the importance of screening, and risk factors, especially within the target population	"It was a hassle trying to get an appointment for a mammogram at the public center, so we ended up going to private sector."
		• Lack of doctor involvement in patient care	
		• Preference for private sector services due to perceptions of higher quality	

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exacerbates these issues. Furthermore, there is a notable lack of data quality control mechanisms to ensure the accuracy and reliability of the information collected. These challenges significantly hinder the effective management and evaluation of cancer screening programs. The primary finding of Tarver et al. is that the positive impact of Health Information Technology (HIT) varies across the cancer continuum. Specifically, analyses targeting diagnosis and treatment were less likely to find a beneficial effect when compared to analyses targeting prevention (27). Mohammadi et al. found that the quality of cancer registry data is relatively low regarding completeness and validity (28). Mosquera reports that the population register is neither accurate nor complete, and it is not updated in a timely manner with changes in contact information (23). Nease and colleagues found that a reminder system led to increases in cancer screening in primary care practices (29). However, based on the literature HIT interventions targeted to patients were less likely to find a beneficial outcome than articles that use HIT interventions targeted to physicians. It seems that various applications of HIT can be used differently throughout the different continuum levels such as prevention, detection, diagnosis, and treatment. Despite the need for a less complex system relative to treatment facilities, there remains a significant gap in the development of an accurate and comprehensive information system for recording client data at screening centers in our country.

A major identified problem is the lack of an effective referral system and the disconnect between primary and secondary care levels within the screening pathway. Key barriers in the managerial dimension include the absence of a mechanism for identifying and inviting women eligible for cancer screening, as well as inadequate monitoring of non-responders to follow-up. Population-based screening is a pathway that begins with the identification of each individual within the target population, followed by personalized invitations and continuous follow-up throughout the entire clinical pathway. This approach ensures equitable access to screening, diagnostic, and treatment procedures. However, when the healthcare system is fragmented, hindering patients from navigating the full continuum of care, diagnostic delays are likely to occur. To improve the referral system, healthcare settings should adopt a more comprehensive approach that integrates multiple elements such as clinician education, organizational culture change, continuous quality improvement, and coordination between public health and therapeutic care levels.

Overcrowding during peak times, long waiting periods, inaccurate triage, and lack of general practitioners (GPs) at the primary level of public healthcare were the identified barriers in service delivery in cancer screening. The delivery of effective diagnostic and treatment services relies on robust program management and the establishment of comprehensive networks of providers across the community. The provision of appropriate and timely clinical preventive services is essential to reduce the morbidity and mortality associated with breast cancer. Effective cancer screening programs should accurately identify women eligible for breast cancer screening and ensure access to comprehensive diagnostic and treatment services within a reasonable timeframe. While lack of general practitioners (GPs) at the primary level of public was a critical factor in inaccurate triage. Richardson et al. emphasized that women with an abnormal screening test should undergo a comprehensive diagnostic evaluation within 60 days, followed by the initiation of treatment within 60 days after diagnosis. This timeline is particularly important because uninsured women, ethnic minorities, and those with lower socioeconomic status are at a greater risk of delays and incomplete follow-up after an abnormal screening result (30). Some participants reported experiencing more than two-month delay in the diagnostic process due to a lack of available physicians in the EDC center which can be associated with a more advanced stage of disease at diagnosis and poorer survival (31, 32). Simultaneously, educating primary care providers to identify the early signs and symptoms of breast cancer is essential for timely referrals within the healthcare system.

The interviews with women revealed several barriers to breast cancer screening, primarily related to their knowledge and attitudes. These barriers include insufficient awareness, low perceived risk, fear and anxiety regarding cancer, inadequate family support, and cultural and religious considerations to examinations. Muslim women often hold socio-ethical, cultural, and religious misconceptions about health, practices, and the nature and causes of breast cancer. Cultural barriers and religious values have been shown to influence their health behaviors, such as maintaining modesty when selecting health interventions (33). Based on a review, the most common barriers to breast cancer screening across populations were race/ethnicity, low socioeconomic status, and educational levels, as well as lack of family history of cancer and being single (34). Some individual-level barriers, such as limited reach of the program, and low health literacy, were consistent with findings from other studies (7, 35, 36). To increase patient demand for cancer screening, it is essential to expand health education initiatives. Previous studies have indicated that nearly 60% of women did not know how to perform breast self-examinations (BSE) (37–39). Allaire et al. emphasized patient navigation as an essential technique for delivering timely and high-quality cancer screening to medically underserved women. This strategy is expected to enhance both life-years and overall health outcomes (30).

Popalis et al. report that educational sessions with community health workers or one-on-one patient interactions can improve cancer screening (40). Other research recommends several interventions that consistently enhance participation in cancer screening, including patient navigation strategies, pre-screening reminders (41), general practitioner endorsement, educational outreach, peer counseling, and small media initiatives (42).

Strengths of the study

One of the key strengths of this study is the use of triangulation, which enhances the reliability and validity of the findings. By employing a combination of interviews, direct observations, and document analysis, the study integrates multiple perspectives and sources of data, allowing for a more comprehensive understanding of the breast cancer screening workflow. In the qualitative phase, we interviewed with two groups—women undergoing screening and healthcare professionals involved in the process—provide valuable insights from both the patient and provider perspectives. This approach not only helps to validate the findings through

cross-referencing but also captures a holistic view of the screening process, including potential challenges, patient experiences, and professional practices.

Limitation

This study encountered a few limitations; firstly, we used a convenience sample in the women group and they were selected from the comprehensive health service and early detection cancer units. Although we continued interviews until saturation, it is unclear that our participants are representative of other patient populations. Meanwhile, we did not categorize the women-based demographics, health literacy, or other factors that might have an effect on their perspectives. Secondly, by design, qualitative research has limited generalizability, although because of lack of data, we have not any choices to catch the challenges in cancer screening program.

Conclusion

This study identifies key barriers to implementing breast cancer screening programs in Iran, including infrastructural deficiencies, managerial inefficiencies, and service delivery challenges. Inadequate facilities and HRH, ineffective referral systems significantly hinder the CSP effectiveness. To improve the referral system, healthcare settings should adopt a more comprehensive approach that integrates multiple elements such as clinician education, organizational culture change, continuous quality improvement, and coordination between departments. Additionally, barriers related to knowledge, perceived risk, and cultural factors among women further complicate screening efforts. To overcome barriers to breast cancer screening among women, strategies should focus on increasing awareness through educational campaigns and improving the accessibility of screening services. Overcoming these barriers is crucial to improving the accessibility, efficiency, and overall effectiveness of breast cancer screening programs, ultimately enhancing patient outcomes. It needs to emphasize, performing a situational analysis in each country in terms of the political, economic, and social context; infrastructure (equipment, facilities, HIT), HRH capacity, financial resources, healthcare system capacity, public awareness, legal and regulatory frameworks, and cultural factors is necessary before introducing any new intervention.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Ethical Review Committee of Ahvaz Jundishapur University of Medical Sciences (ethics code: IR.AJUMS.REC.1402.552). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AJ: Formal analysis, Writing – original draft, Data curation. ZN: Formal analysis, Conceptualization, Supervision, Validation, Writing – original draft, Writing – review & editing. SO: Data curation, Writing – review & editing. SL: Data curation, Writing – review & editing. RB: Data curation, Writing – review & editing. MB: Data curation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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Health workers' motivation was significantly higher in private hospitals than public hospitals influenced by intrinsic and extrinsic factors in Northwest Ethiopia

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Background: Motivation of health workers is crucial for providing high-quality healthcare services and improving the performance of health facilities. However, less attention has been given to this aspect of workplace climate in hospital settings, and there is scant evidence on the level of health workers' motivation on healthcare delivery. Therefore, this study aimed to assess the motivation of health workers and its determinants at public and private hospitals in Bahir Dar City, Northwest Ethiopia.

Methods: A facility-based comparative cross-sectional study was conducted from November 3rd to December 4th, 2021. A simple random sampling technique was used to select 472 study participants. Motivational status was measured using the mean of 14 items on a Likert scale. Descriptive statistics were computed to present results using tables and figures. Bi-variable and multivariable logistic regressions were performed to identify factors associated with motivational status. Strength of association was measured using adjusted odds ratios with the corresponding 95% confidence intervals and statistical significance was declared at p-values less than 0.05.

Results: A total of 458 health workers participated in our study the health workers' motivational status was found to be 56.3% (95% CI: 52–60.7%). A significant difference in motivational status was observed between private (62.3%) and public hospitals (50.4%) ($\chi^2 = 6.532$, $p = 0.011$). Working in private hospitals (AOR = 1.52; 95% CI: 1.03–2.23), good collegial relationships (AOR = 1.61; 95% CI: 1.1–2.32), job satisfaction (AOR = 1.49; 95% CI: 1.02–2.20), a favorable work environment (AOR = 1.56; 95% CI: 1.06–2.30), and educational status (AOR = 0.4; 95% CI: 0.17–0.94) were significantly associated with higher health workers' motivational status.

Conclusion: The motivational status of health workers was significantly higher in private hospitals than in public hospitals. The proportion of motivated health workers was low, which poses challenges in maintaining a regulated health workforce within the health system. Working in private hospitals, job satisfaction, working environment, higher educational status, and collegial relationships were predictors of motivational status. Therefore, public hospitals should promptly implement both intrinsic and extrinsic motivational strategies.

KEYWORDS
motivation, public and private hospitals, health workers, Bahir Dar City, Ethiopia

Introduction

In the workplace, motivation is defined as an individual's willingness to exert and sustain effort. It encompasses the readiness to work productively toward achieving organizational goals. Motivated individuals are energized to overcome challenges and enhance their accomplishments. Therefore, motivation plays a crucial role in maximizing organizational performance (1–3). According to Herzberg's two-factor theory, motivation can be categorized into two types: extrinsic and intrinsic motivation. Intrinsic motivation originates from within individual workers and is often associated with factors such as job satisfaction, recognition, achievement, and advancement. Conversely, extrinsic motivation is linked to external factors such as incentives, the working environment, and management practices (4–6). Intrinsic and extrinsic motivators are not entirely independent of each other; rather, they exhibit an inverse relationship. Intrinsic motivators tend to enhance motivation when they are present, while extrinsic motivators have the potential to diminish motivation when they are lacking (7).

Motivation in healthcare delivery positively impacts quality and patient safety (8). In a decentralized governing system, a motivated workforce is essential for developing a well-functioning health system (9). Resources availability and professional competencies are not sufficient to attain health system goals without adequate motivational packages (10–13). Healthcare delivery is a time-consuming and complicated system. Highly motivated health workers are required to meet the patients' desired expectations and competing clinical issues (14). In Ethiopia, the Ministry of Health has introduced different reforms and approaches such as business process re-engineering, healthcare financing, and health information systems to improve the quality of healthcare by adhering to a strong management system (15, 16). However, the health system is currently experiencing high turnover rates, with trained health professionals, particularly in the public sector, migrating and leaving their positions (17–19).

In Ethiopia, health workers across various disciplines in hospital settings were not adequately motivated. Only a quarter (25.1%) of health workers in Jimma Comprehensive Specialized Hospital reported being motivated (14). In central Ethiopia, it was reported that the level of motivation among health workers accounted for 63.63% (20). In Gedeo zone, Ethiopia, it was found that 50% of health workers were not motivated. Only 19.5% of health workers working in health centers were highly motivated (21). In public hospitals of west Amhara and Debre Markos Comprehensive Specialized Hospital, the level of motivation among health workers reached 58.6 and 20.4%, respectively (16, 22). Studies that were conducted abroad to Ethiopia revealed that health workers motivation was 42.7% in Cameroon (23), 75.55% in Kenya (24),

Recognizing and addressing the demotivating factors is a central dimension of managing employees' motivation (25, 26). Herzberg's two-factor theory is relevant to human resource management in the health sector. It identifies company policy and administration, supervision, interpersonal relations, working conditions, and salary as hygiene factors of motivation (27). Workers are motivated not only by extrinsic rewards but also by the desire to fulfill their psychological needs, such as autonomy, competence, and relatedness (28). Fort and Voltero in Armenia revealed that performance improvement regarding maternal healthcare was enhanced following incentives to the providers in the form of recognition, in-kind contributions, community respect, and assistance with services (29). In Uganda, it was evidenced that unfavorable working conditions, low remuneration, and lack of recognition and promotion were contributing to the inadequate level of health workers' motivation (30). Good management, supportive supervision, and positive relationships with colleagues were identified as factors that enhance health workers' motivation (31–34). It was also evidenced that health workers were motivated to perform better when provided with training opportunities, promotions, conducive working environment, effective leadership and management, competitive salaries, and manageable workloads (35–37). The motivation level of health workers was significantly related to factors such as their age, educational level, work experience, administrative positions, financial benefits, and communication (38). Job satisfaction, training opportunities and advancement in professional carriers are among positively contributing factors for higher level of health workers motivation (22, 39, 40).

Strategic human resource management has been taken into account as important tool to motivate and maintain healthcare professionals (41). The poor motivation of health workers contributes to the weakness of many nations' health systems. However, adequate attention has not been provided for this significant issue of healthcare delivery system. While some studies have attempted to examine health workers' motivation in Africa, their measurements were not aligned with the contexts of developing nations (20, 42, 43). To the best of the authors' knowledge, few studies on health workers' motivation have been conducted in Ethiopia. However, evidence is very limited in the study area. Thus, this study aimed to determine the level of health workers' motivation and its associated factors at public and private hospitals in Bahir Dar City. our study was also intended to compare health workers' motivation between public and private hospitals.

Materials and methods

Study design and setting

A facility-based comparative cross-sectional study was conducted from November 3rd to December 4th, 2021, in Bahir Dar City, located 565 kilometers away from Addis Ababa, the capital City of Ethiopia. Both private and public hospitals were included as study institutions. According to the Municipality report (2021), Bahir Dar City has a total population of 345,084 residents (44). There are three public hospitals (Felege-Hiwot Comprehensive Specialized Hospital, Tibebe-Gion Comprehensive Specialized Hospital, and Addis Alem Primary Hospital) and four private hospitals (Dream Care, Gamby, Adinas, and Afilas General Hospitals) in the City. The hospitals are currently

Abbreviations: AOR, Adjusted Odds Ratio; BSc, Bachelor Science; CI, Confidence Interval; COR, Crude Odds Ratio; SD, Standard Deviation; SPSS, Statistical Package for Social Science.

servicing more than 5 million populations in outpatient, emergency, inpatient, and maternity units for essential healthcare including medical, surgical, pediatrics, orthopedics, ophthalmic, and obstetric-gynecologic services. These hospitals are currently employed by 1820 health workers.

Study participants and eligibility criteria

The study participants were healthcare professionals of all disciplines including physicians, nurses, midwives, pharmacists, anesthetists, health officers, physiotherapists, and laboratory technologists who were working in public and private hospitals in Bahir Dar City administration. All healthcare workers employed in these hospitals constituted the source population. We included all full-time working health professionals with a work experience of 6 months or more. However, we excluded healthcare professionals who were newly employed and had maternal or annual leave during the data collection period.

Sample size determination

The sample size for objective one was calculated using the double-population proportion (public hospitals and private hospitals) formula. We considered a 95% confidence interval, a 5% margin of error, a 58.3% proportion (P1) for public hospitals taken from a recent study in Ethiopia (39), a 50% proportion (P2) for private hospitals, as there was no previous study in Ethiopia, and 10% for non-response rate. Accordingly, a sample size of 561 was estimated. For objective two, the sample size was estimated considering a 95% confidence interval, 80% power, and a 10% non-response rate, based on significantly associated factors from previous studies (14, 39). The maximum sample size was 374. Since the largest sample size was taken for objective one, the final sample size was determined to be 561 (281 for each of public and private hospitals) using a 1:1 ratio.

Sampling procedure

The study participants were selected from all three public and four private hospitals in the City administration. The study populations were homogeneous since all were health professionals, and the study units were grouped by their working facility. The required sample size for each public and private hospital was allocated proportionally based on the number of health workers: 151 health workers in Felege-Hiwot Comprehensive specialized hospital, 100 in Tibebe-Gion Comprehensive specialized hospital, 28 in Addis Alem Primary hospital, 69 in Dream Care, 100 in Gamby, 73 in Adinas, and 37 in Afilas general private hospitals. The study participants from each hospital were selected using a simple random sampling technique.

Study variables

Dependent variable

The health workers' motivational status was outcome variable of our study.

Independent variables

Socio-demographic variables include age, sex, marital status, religion, profession, workplace, work experience, monthly salary, educational status, and managerial position. Intrinsic factors comprised of achievement, recognition, advancement, and responsibility, while extrinsic factors include collegial relationships, working environment, remuneration, justice and fairness, and resource availability. Additionally, job satisfaction, performance appraisal, salary/career structure, duty payment, working hour schedule, and transportation were considered.

Operational definitions

Health workers in this study refer to healthcare providers who were full-time employees of public or private hospitals, including physicians, nurses, midwives, pharmacists, laboratory technologists, anesthetists, health officers, and others such as physiotherapists, radiographers, and environmental health specialists. Motivational status was measured using 14 items of general motivation questions. Health workers were asked to provide their responses using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The health workers' motivation was dichotomized into "motivated" and "not motivated" based on the calculated cut-off point (mean = 3.2). If the mean score of the respondent equaled or exceeded the overall mean, we considered the health worker as motivated. Conversely, if it was below the overall mean, we considered the health worker as not motivated (14, 45).

Data collection tools and procedures

A self-administered structured questionnaire tool was adopted from similar studies conducted in Ethiopia and Zambia (14, 39, 46) and used to collect the data. The questionnaire was prepared in English and comprised of sections on socio-demographic characteristics, factors influencing motivation, and motivational status. Data collection was conducted by two trained diploma nurses, with supervision provided by a BSc nurse.

Data quality control

A validated data collection tool was adopted and pre-tested using 5% of the sample size outside of the study hospitals. Internal consistency (reliability) of Likert Scale questions was checked by calculated Cronbach's alpha value which was 0.86 in our study. One day of training for data collectors and supervisors was provided regarding instrument contents and data collection procedures. Data completeness and consistency were checked daily by the authors and supervisor.

Data analysis and management

Epi-Data version 3.1 was used for data entry and cleaning. The data were then exported to SPSS version 23 for statistical analysis.

Descriptive statistics were employed to present study results through tables and figures. The Chi-square (χ^2) test was computed to assess the difference in motivational status between public and private hospitals. Binary logistic regression was used to examine the association between dependent and independent variables. Explanatory variables with *p*-values less than 0.25 in the bivariable analysis were considered as candidates for multivariable analysis. Significant associations were identified and interpreted using an adjusted odds ratio with a 95% CI at *p*-value less than 0.05. The model's fitness was checked using the Hosmer-Lemeshow goodness-of-fit test ($p = 0.568$). Multicollinearity was assessed using the variance inflation factor (VIF).

Results

Socio-demographic characteristics

A total of 458 health workers, 230 from public hospitals and 228 from private hospitals, responded to the research questions, resulting in a response rate of 81.5%. The mean age of the respondents was 31.38 ± 5.70 (SD) years. The majority of health workers (60%) were male. Approximately, two-thirds of the participants (66.6%) were married. Regarding religion, the majority (85.8%) were identified as Orthodox Christian followers. Nurses constituted the largest group of health workers followed by physicians, accounting for 33 and 19.9%, respectively. More than half of the respondents (54.6%) held a bachelor's degree as their highest qualification. A large proportion of the participants (43.9%) had 1–5 years of work experience. Overall, the average monthly salary was 9351.70 ± 8084.39 (SD) in Ethiopian birr. Sex, age, marital status, work experience, educational status, and monthly salary characteristics showed significant variation between public and private hospital employees (Table 1).

Extrinsic factors of motivation

Eighty-two (35.7%) and 118 (51.8%) health workers employed in public and private hospitals, respectively, perceived the working environment as favorable. More than half of public (57%) and private (56.1%) health workers reported having poor and good collegial relationships, respectively. The majority (65.2%) of public health workers indicated inadequate drug, supply, and equipment availability in their hospitals, while 52.6% of private health workers reported adequate supply and drug availability. Regarding extrinsic factors, significant variations were observed between public and private hospital employees, particularly in interpersonal relationships and remuneration factors (Table 2).

Intrinsic factors of motivation

Ninety-seven (44.3%) respondents in public hospitals and 107 (46.9%) in private hospitals, believed that they had achieved. Only 105 (45.7%) participants from public hospitals and 97 (42.5%) from private hospitals explained that they had advanced in their careers. In private hospitals, the majority of respondents (65.4%) perceived that they had been recognized for their better performance, while in public hospitals, only 32.2% of the respondents explained that they were provided recognition. A significant difference was observed in the recognition factor between public and private hospital employees (Table 3).

Job satisfaction

The overall job satisfaction level of healthcare workers was 52%. There was a statistically significant difference in job satisfaction based on employment status ownership ($\chi^2 = 10.69$, $p < 0.001$). Job satisfaction among private hospital workers (55.7%) was higher than among public hospital workers (40.4%) (Figure 1). Better recognition in private hospitals increased employees' job satisfaction, while improved compensation and staff relationships in private hospitals decreased employees' job dissatisfaction.

The motivational status of health workers

The proportion of motivated health workers was revealed to be 56.3% (95% CI: 52–60.7). It was 50.4 and 62.3% for public and private hospital employees, respectively. The study showed a significant difference in the health workers' motivational status between public and private hospitals in Bahir Dar City ($\chi^2 = 6.53$, $p = 0.011$) (Figure 2).

Factors associated with the health workers' motivational status

The current study demonstrated that there was a strong relationship between type of hospital ownership and the health workers' motivational status. Health workers who were working in private hospitals were 1.52 times more likely to be motivated when compared to those who were working in public hospitals (AOR = 1.52, 95% CI: 1.03–2.23). The odds of motivational status of respondents with good collegial relationship were 1.61 times more likely to be motivated than their counter parts (AOR = 1.61 at 95%CI = 1.10–2.36). Health workers who were satisfied in their jobs were 1.49 times more likely to be motivated than those who were not satisfied (AOR = 1.49, 95% CI: 1.02–2.20). The motivational status increased by 1.56 times among respondents who were working in a favorable working environment compared to those who were working in unfavorable conditions (AOR = 1.56, 95% CI: 1.06–2.30). Health workers who hold a Master's degree showed a 60% reduction in the level of motivational status compared to those with a diploma (AOR = 0.40, 95% CI: 0.17–0.94). Our study revealed that extrinsic factors were more pronounced in hospitals of Bahir Dar City (Table 4).

Discussion

Enhancing the quality of healthcare services, lowering burnout, and guaranteeing patient satisfaction all depend on motivating healthcare professionals. Motivational techniques should take into account social, professional, and economical aspects in Ethiopian

TABLE 1 Socio-demographic characteristics of health workers at hospitals in Bahir Dar City, Northwest Ethiopia, 2021.

Characteristic	Category	Health institutions (n = 458)		χ^2 (p-value)
		Public-230	Private-228	
Sex	Male	74(32.2)	109(47.8)	11.6(0.001)
	Female	156(67.8)	119(52.2)	
Age	≤24	7(3)	20(8.8)	16.3(0.003)
	25–29	68(29.6)	89(39)	
	30–34	95(41.3)	80(35.1)	
	35–39	34(14.8)	17(7.5)	
	>40	26(11.3)	22(9.6)	
Religion	Orthodox	201(87.4)	192(84.2)	0.3(0.86)
	Protestant	15(6.5)	24(10.5)	
	Muslim	14(6.1)	12(5.3)	
Marital status	Single	63(27.4)	84(36.8)	6.45(0.04)
	Married	154(67)	138(60.5)	
	Others [a]	13(5.7)	6(2.6)	
Profession	Midwifery	31(13.5)	31(13.5)	3.85(0.57)
	Nurse	81(35.2)	70(30.7)	
	Physician	47(20.4)	44(19.3)	
	Laboratory	26(11.3)	24(10.5)	
	Pharmacy	22(9.6)	23(10.1)	
	Others [b]	23(10)	36(15.8)	
Work experience	<1 year	2(0.9)	31(13.5)	31(0.000)
	1–5 years	102(44.3)	99(43.4)	
	6-10 years	73(31.7)	66(28.9)	
	>10 years	53(23)	32(14)	
Educational status	Diploma	20(7.8)	71(31.1)	43.4(0.000)
	Degree	149(64.8)	101(44.3)	
	Masters/above	61(26.5)	56(24.6)	
Monthly salary in ETB	<6,000	25(10.9)	96(42.1)	62.2(0.000)
	6,001–10,000	148(64.3)	80(35.1)	
	>10,000	57(24.8)	52(22.8)	
Managerial position	Yes	19(8.3)	23(10.1)	
	No	211(91.7)	205(89.9)	

[a]: divorced or widowed, others. [b]: Anesthetist, health officer, radiologists, environmental, physiotherapy, χ^2: Chi-Square.

healthcare systems, as well as those in other countries (26). Motivated health workers are energetic to exert their creative potentials in healthcare delivery and can apply their knowledge and skills in establishing goal oriented health system (39). The present study was conducted to determine the level of health workers motivation and to identify associated factors in both private and public hospitals of Bahir Dar City.

Our study revealed that the overall motivational status among health workers of hospitals in Bahir Dar City was 56.3%. This finding is almost similar to other findings from Gedeo zone (Southern Ethiopia), Amhara (Northwest Ethiopia), Arsi zone (Oromia region), and Jimma town (Southwest Ethiopia) which reported 54.8, 58.6, 58.3, and 54.5% motivational status, respectively (16, 21, 39, 45). The possible explanation for these congruent findings might be the similarity among study participants in terms of socio-economic background, professional qualifications, and the context of the health system. However, the motivational status in our study was higher than the findings in Jimma University Specialized Hospital (Ethiopia) and Franko Division Hospital (Cameroon), where the motivational statuses were reported as 25.1 and 42.7%, respectively (14, 23). This discrepancy could be attributed to differences in the study settings, as our study included both public and private hospitals, whereas previous studies were conducted solely in public hospitals. Additionally, the motivational status in this study was lower than that reported in other findings from West Shewa zone (Central Ethiopia) and Gaza

TABLE 2 Perceptions of extrinsic motivational factors among health workers at hospitals in Bahir Dar City, Northwest Ethiopia, 2021.

Variables	Category	Health institutions (n = 458)		χ^2 (P-value)
		Public	Private	
Working environment	Favorable	82(35.7)	118(51.8)	0.01(0.92)
	Not favorable	148(64.3)	110(48.2)	
Interpersonal relationship	Good	99(43)	128(56.1)	7.86(0.005)
	Poor	131(57)	100(43.9)	
Justice and fairness	Fair	114(49.6)	123(53.9)	0.88(0.35)
	Unfair	116(50.4)	105(46.1)	
Supply, drugs, and equipment	Adequate	80(34.8)	120(52.6)	0.137(0.711)
	Inadequate	150(65.2)	108(47.4)	
Remuneration	Remunerated	83(36.1)	105(46.1)	4.7(0.03)
	Not remunerated	147(63.9)	123(53.9)	

χ^2: Chi-square.

TABLE 3 Health workers' perception of intrinsic factors of motivation at hospitals in Bahir Dar City, Northwest, Ethiopia, 2021.

Variables	Category	Health institutions		χ^2 (P-value)
		Public	Private	
Achievement	Achieved	102(44.3)	107(46.9)	0.31(0.579)
	Not achieved	128(55.7)	121(53.1)	
Advancement	Advanced	105(45.7)	97(42.5)	0.449(0.503)
	Not advanced	125(54.3)	131(57.5)	
Recognition	Recognized	74(32.2)	149(65.4)	50.446(0.0001)
	Not recognized	156(67.8)	79(34.6)	

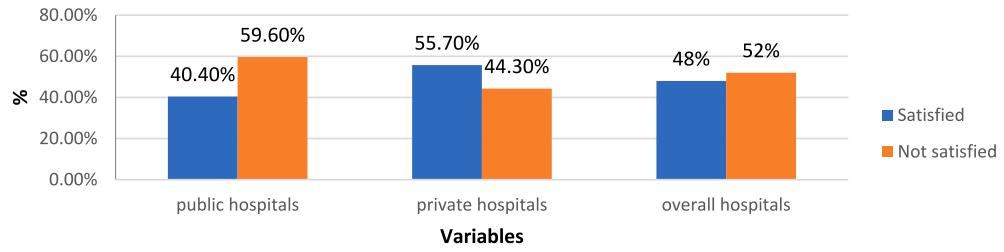


FIGURE 1
Job satisfaction among healthcare professionals in public and private hospitals in Bahir Dar City, 2021.

Hospital (Europe), where motivational statuses of 63.63 and 66.2% were reported, respectively (20, 47).This disparity might be attributed to differences in the study period, settings, and design. In our study, the motivational status of health workers in private hospitals was significantly higher than in public hospitals (48, 49). This finding is consistent with previous research conducted in Bahir Dar and Hawassa Cities. The possible explanation for this difference might be due to disparities in goals, resources, and incentives between the facilities.

Health workers who had good collegial relationships were 1.61 times more likely to be motivated than those who had poor relationships. This finding is congruently similar to another study conducted in Jimma Comprehensive Specialized Hospital (14). It confirms the fact that having positive relationships with colleagues and staff in the workplace inspires individual workers and contributes to their motivation. Additionally, it was revealed that health workers who were satisfied in their job were 1.49 times more likely to be motivated compared to their counterparts. This finding was supported by previous research conducted in Jimma and West Arsi, Ethiopia (14, 39). The explanation for this finding could be that employees who are satisfied with their job tend to be more motivated to be productive in their tasks. Another significant

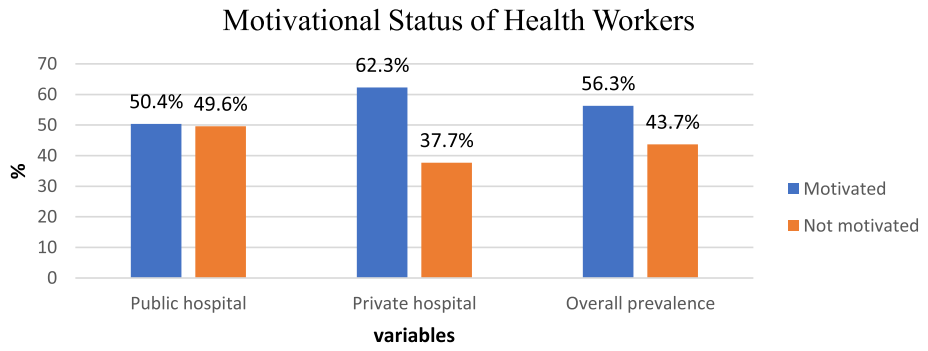


FIGURE 2
Motivation status among public and private hospitals in Bahir Dar City, 2021.

TABLE 4 Factors associated with the motivational status among health workers at hospitals in Bahir Dar City, Northwest, Ethiopia, 2021.

Variables	Category	Motivational status		COR(95% CI)	AOR(95% CI)
		Motivated	Not-motivated		
Hospital ownership	Public	116(50.4)	114(49.6)	1	1
	Private	142(62.3)	86(37.7)	1.62(1.12, 2.35)	1.52(1.03, 2.23)*
Achievement	Achieved	131(62.7)	78(37.3)	1.61(1.11, 2.35)	1.36(0.92, 2.01)
	Not achieved	127(51.0)	122(49.0)	1	1
Supply, drugs and equipment	Adequate	133(60.7)	86(39.3)	1.41(0.97, 2.05)	1.03(0.68, 1.56)
	Inadequate	125(52.3)	114(47.7)	1	1
Working environment	Favorable unfavorable	127(63.5) 131(50.8)	73(36.5) 138(49.2)	1.69(1.16, 2.46)	1.56(1.06, 2.30)*
Job satisfaction	Satisfied	139(63.2)	81(36.8)	1.72(1.18, 2.50)	1.49(1.02, 2.20)*
	Not satisfied	119(50)	119(50)	1	1
Interpersonal relationship	Good	141(63.8)	80(36.2)	1.81(1.24, 2.63)	1.61(1.10, 2.36)*
	Poor	117(49.4)	120(50.6)	1	1
Remuneration	Remunerated	113(60.1)	75(39.9)	1.30(0.89, 1.89)	0.98(0.64, 1.52)
	Not-remunerated	145(53.7)	125(46.3)	1	1
Educational level	Diploma	58(63.7)	33(36.3)	1	1
	Degree	143(57.2)	107(42.8)	0.76(0.46, 1.25)	0.89(0.52, 1.52)
	Master	13(37.2)	22(62.9)	0.34(0.15, 0.75)	0.40(0.17, 0.94)*
	GP/Specialist	44(53.7)	38(46.3)	0.66(0.36, 1.21)	0.74(0.40, 1.40)
Monthly salary (ETB)	≤6,000	79(65.3)	42(34.7)	1	1
	6,001–10,000	121(53.1)	107(46.9)	0.60(0.38, 0.95)	0.72(0.41, 1.28)
	≥10,000	58(53.2)	51(46.8)	0.61(0.36, 1.03)	0.86(0.37, 1.98)
Managerial position	Yes	20(47.6)	22(52.4)	0.68(0.36, 1.28)	0.67(0.34, 1.32)
	No	238(57.2)	178(42.8)	1	1

*$p < 0.05$; 1 = reference category.

predictor of health workers' motivational status in our study was the presence of a favorable working environment. Health workers who worked in a favorable climate were 1.56 times more likely to be motivated than those who worked in an unfavorable climate. Similar findings were reported in other studies conducted in Gedeo zone, Ethiopia, and India (21, 50). This finding aligns with Herzberg's two-factor theory. It might be due to the fact that less stressful working climate might favor motivation. Interestingly, more qualified health workers were found to be less motivated than those with lower educational qualifications. This finding aligns with studies conducted in Saudi Arabia, Europe, and Jimma town, Ethiopia (38, 45, 51). The possible explanation for this finding might be due to an increased expectation from educated health workers regarding the incentive packages, leading and managing opportunities. The unmet condition on these expectations might pose them less motivated.

Study strengths and limitations

Considering health workers both working at public and private hospitals is strength of our study which the previous studies did not touch. However, it was not done without limitations. As a cross-sectional study design was employed, establishing a true causal-effect relationship was limited. Data collection during working hours might have caused respondents to be less focused due to work overload. Our study did not incorporate a qualitative approach.

Conclusion and recommendations

The overall motivation of health workers in Bahir Dar City public and private hospitals is 56.3% which is low; challenges may be posed to maintain a regulated health workforce within the health system. Our comparison analysis revealed that motivation among health professionals was significantly higher in private hospitals than public hospitals. The overall motivational status was statistically predicted by job satisfaction, working climate, collegial relationships, educational qualification, and hospital ownership factors. Furthermore, improved compensation and staff relationships were found to decrease employee dissatisfaction, while better recognition enhanced job satisfaction, particularly in private hospitals than public hospitals. Therefore, public hospitals should promptly implement both intrinsic and extrinsic motivational strategies. Hospital administers of both sectors should focus on strategies of human resource management to increase motivated health workers through addressing financial, professional and social factors.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Institutional Review Board (IRB) of the College of Medicine and Health Sciences, Bahir Dar University, with protocol number CMHS 0015-16-2021. The selected hospitals were contacted for official permission. Written informed consent for participation was obtained from each respondent. Participants were informed that their participation was voluntary and that they had the right to stop or withdraw at any stage.

Author contributions

DA: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Supervision, Validation, Visualization, Writing – original draft. GA: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft. MH: Conceptualization, Formal analysis, Investigation, Project administration, Software, Supervision, Validation, Visualization, Writing – original draft. AA: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Data-driven segmentation of type 2 diabetes mellitus patients: an observational study on health care utilisation prior to an emergency department visit in Germany

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Background: Potentially avoidable hospital admissions (PAHs) due to type 2 diabetes mellitus (T2DM) occur more frequently in Germany than in the rest of Europe. Emergency departments (EDs) play an important role in understanding cross-sectoral health care utilisation resulting in inpatient admissions. Segmenting T2DM patients in homogenous groups according to their health care utilisation may help to understand the population's needs and to allocate limited resources. The aim of this study was to describe ED use and subsequent inpatient admissions among T2DM patients, and to segment the study population into homogenous subgroups based on disease stage, health care utilisation and process quality of outpatient care prior to an ED visit.

Methods: This study was conducted as part of the INDEED project, comprising data on 56,821 ED visits in 2016 attributable to 40,561 patients with T2DM from 13 German EDs, as well as statutory health insurance claims data from 2014 to 2016 retrospectively linked per patient. Descriptive analyses included patient characteristics, ED admission diagnoses and discharge diagnoses in the case of inpatient admission of T2DM patients to the ED. Latent class analysis was conducted to identify different subgroups of T2DM patients based on disease stage, number of physician contacts and medical examinations prior to the ED visit.

Results: Almost half of the study population had severe comorbidities (44.3%). In addition to T2DM, multiple cardiovascular diagnoses were among the most frequently documented admission and discharge diagnoses. The proportion of hospitalised ED visits for T2DM patients was higher (59%) than that for the INDEED population (42.8%). We identified three latent classes that were characterised

as *"early disease stage and high utilisation"* (36.5% of the study population), *"progressing disease stage and low utilisation"* (26.1%) and *"progressed disease stage and high utilisation"* (37.4%).

Conclusion: A substantial share of T2DM patients had not received disease monitoring according to guideline recommendations prior to ED presentation. Improving guideline-adherence in the outpatient sector could help reduce potentially avoidable ED visits. Effective interventions that aim at improving continuity and quality of care as well as reducing the share of PAH need to be identified and evaluated per identified class.

KEYWORDS

type II diabetes mellitus, emergency department, health care utilisation, avoidable hospital admission, population segmentation, latent class analysis

1 Introduction

Type 2 diabetes mellitus (T2DM) is a chronic metabolic disease characterised by elevated blood glucose levels. In Germany, 8.6% (95% CI: 7.4–10.0%) of women and 9.9% (95% CI: 8.6–11.3%) of men aged 18 to 79 are affected by known and unknown diabetes mellitus (DM) (1). The prevalence of known DM in Germany (8.4%; 95% CI: 7.8–8.9%) is thus higher than the EU average of 7.4% (95% CI: 7.3–7.6%) (2, 3). In the adult population, T2DM is the most common type of diabetes mellitus, accounting for more than 90.0% of all diagnosed cases (4, 5). Despite existing treatment guidelines and the high potential for preventing disease progression, DM frequently leads to comorbidities, including diseases of the cardiovascular system, kidney failure, diseases of the eye and amputations of the lower extremities (4). Due to the high burden of disease and the high economic burden on healthcare systems, DM constitutes a substantial challenge for public health (6).

DM is classified as an ambulatory care sensitive condition (ACSC) (7, 8), i.e., DM-related inpatient admissions can be avoided with adequate, guideline-based outpatient treatment (9). Potentially avoidable hospital admissions (PAHs) due to T2DM are defined as a key indicator to measure quality of care in the outpatient sector by the Organisation for Economic Co-operation and Development (OECD) and are monitored as part of the German Diabetes Surveillance (2, 62). With an inpatient admission rate of 206 per 100,000 people, Germany has high levels of PAH due to DM compared to the EU average admission rate of 139 per 100,000 people (2). In addition, DM is also a risk factor for other diseases leading to PAH: In a French cohort of patients with DM, congestive heart failure and chronic obstructive pulmonary disease (COPD) were the two most common causes of inpatient treatment due to an ACSC, while short-term complications due to DM ranked third (10). A Portuguese study on the impact of DM on multiple inpatient admissions showed that inpatients diagnosed with DM had a longer average length of stay and higher costs (11). In Germany, the prevalence of DM in inpatient cohorts is twice as high as in the general population, and inpatient mortality is increased by up to 30% in individuals with T2DM compared to non-diabetics (12).

Continuous, coordinated care across sectors is crucial for preventing PAHs (9). Mapping and improving cross-sectoral care play an important role in the highly fragmented German healthcare system. The financial and organisational separation of the outpatient and inpatient sectors in Germany impairs the coordination and quality of health care services (13). Emergency departments (EDs) form a special interface between the outpatient and inpatient sectors, as they contain components of both sectors (14). While services for patients not admitted as inpatients are billed on an outpatient basis through the associations of statutory health insurance (SHI) physicians organised at the federal state level, services for patients admitted as inpatients are billed directly by health insurance funds (15). With 48.8%, the inpatient admission rate out of all ED visits is significantly higher in Germany than in other European countries (16). EDs thus play a relevant role in understanding cross-sectoral patterns of health care utilisation resulting in inpatient admission. To date, little is known about the cross-sectoral health care utilisation of T2DM patients attending EDs.

To improve cross-sectoral coordination of care and enhance patient management of T2DM patients, it is important to understand health care utilisation resulting in ED visits and inpatient admissions (8). Segmenting the population into homogenous groups according to their health care utilisation contributes to a better understanding of the population's demand and facilitates the effective allocation of limited resources from a population health perspective (17, 18). Usually, in population segmentation methods, a distinction is made between data-driven and expert-driven approaches. In expert-driven approaches, segments of a population are distinguished by a panel of experts or health care practitioners using predefined criteria established through a literature review or a consensus-building process. Data-driven approaches use statistical analyses on extensive datasets to recognise underlying patterns of factors influencing predefined outcomes (18). Regarding T2DM patients, the most studied objectives to date are health grouping, assessment of diabetes-related complications, and non-diabetic metabolic complications. Segmentation variables at the individual level mainly included sociodemographic, DM-related, and non-DM medical-related variables. Variables relating to the healthcare system utilisation are used less frequently (17). To date, no data-driven segmentation analyses have been conducted on the outpatient health care utilisation of T2DM patients prior to an ED visit.

The overall aim of this analysis was to contribute to a better understanding of cross-sectoral patterns of health care utilisation among T2DM patients prior to ED visits with and without subsequent inpatient admissions via ED in Germany. Specifically, the study aimed to (1) describe their outpatient health care utilisation in the year prior to an ED visit, (2) describe their diagnoses in the ED as well as main hospital diagnoses in case of inpatient admission, and (3) identify

homogenous subgroups of T2DM patients regarding disease stage, outpatient health care utilisation and process quality of outpatient health care prior to an ED visit.

2 Methods

2.1 Data source

This study was conducted as part of the explorative multicentre project INDEED (INDEED: Utilisation and cross-sectoral patterns of care of patients in emergency departments in Germany). The overall aim of the INDEED project was to illustrate ED use and to explore cross-sectoral patterns of care for patients admitted to EDs (14, 19). The INDEED dataset used for this study consisted of (1) ED data of SHI insured patients collected from 16 German EDs in 2016 and (2) outpatient claims data from the years 2014–2016. Data were collected and linked for each of the ED patients retrospectively (14). The data set is unique for Germany. A more recent, comparable database with linked ED and outpatient data is not available due to the established data structures and data protection regulations in Germany. Over the last two decades the number of ED cases increased constantly, although this changed during the covid-19 pandemic (20). Nevertheless, the data set is still suitable for investigating cross-sectoral patterns of health care utilisation in Germany.

The ED data included information on patient demographics, ED treatment and ED diagnoses. The ED data were supplemented with the main hospital diagnosis in the case of inpatient admission following the ED visit. Diagnoses were not available for every ED visit or inpatient admission. Three of the 16 EDs did not provide any ED diagnoses and were therefore excluded from further analyses. The outpatient data included information on patient demographics and insurance status, as well as outpatient diagnoses coded according to ICD-10-GM (International Classification of Diseases and Related Health Problems, 10th revision, German Modification) (21), medical procedures coded according to standardised outpatient billing codes (22), and drug prescription data coded according to ATC-codes (Anatomical Therapeutic Chemical Classification) (23). Information on participation in a disease management programme (DMP) appeared to be incomplete, as the numbers of documented participants for all DMPs were significantly lower than the actual numbers recorded by statutory health insurances. It was not possible to ascertain whether this discrepancy was a data artefact or an actual deviation in the study population from the total population, based on the available data. Outpatient data were transmitted from eight associations of SHI physicians in the federal states in which the participating EDs were located (24). One of the eight participating associations of SHI physicians was unable to transmit drug prescription data. Comprehensive information on the participating EDs and associations of SHI physicians as well as the process of data linkage is described elsewhere (19).

The dataset is based on a total of 454,747 ED visits in 2016, attributable to 353,926 patients, who were at least 18 years old in 2014. Furthermore, the dataset only contained ED visits that were billed via the SHI. In 2020, 87% of the German population were covered by statutory health insurance (13). Privately insured patients and visits billed via statutory accident insurance were not included in the dataset (25).

2.2 Study population

2.2.1 Definition

The study population included patients with a validated T2DM diagnosis for which at least one case was documented in the outpatient data. The presence of DM was defined via the ICD-10-GM-Codes (E10.- up to E14.-) (21). In addition, drug prescriptions of insulin and oral antidiabetic drugs (OADs) as well as participation in a DMP (if available) were included for validation of diagnosis and to distinguish between different types of DM. Prescriptions for insulin or OAD were identified via ATC-codes (23). Table 1 provides an overview of the codes considered. Figure 1 illustrates the process of extraction and validation of the study population as outlined below.

2.2.2 Extraction and validation

The extraction of the study population was performed in three steps in accordance with procedures recommended by the Robert Koch Institute (RKI) and the German Institute for Quality and Efficiency in Health Care (IQWiG) (4, 26). (I) All patients with at least one ICD-10-GM code for diabetes mellitus were identified within the dataset. Outpatient diagnoses two years prior to the ED visit, as well as ED diagnoses and the main hospital diagnosis were considered. The period "two years prior to the ED visit" comprised eight quarters prior to the quarter in 2016 in which the ED visit took place for each patient. In the case of multiple ED visits per patient in 2016, the first visit was used as the calculation basis. Only outpatient diagnoses with the addition of "confirmed" or "condition after" were considered to ensure diagnosis validity (5, 26). Inpatient diagnoses are considered valid in the German healthcare system due to standardised coding guidelines with billing relevance (27). (II) The presence of at least one of the following conditions was used to validate the DM diagnosis: (1) DM was coded at least two quarters in the outpatient data two years prior to the ED visit; (2) DM was coded once in the outpatient data two years prior to the ED visit and once as the ED diagnosis in 2016; (3) DM was diagnosed once in the outpatient data two years prior to the ED visit or as the ED diagnosis in 2016, and there was at least one prescription for insulin or OAD in the outpatient data two years prior to the ED visit; or (4) DM was

TABLE 1 Overview of the codes used for study population definition.

Inclusion criteria	Code	Description
Diagnoses according to ICD-10-GM (21)	E10.-	Type 1 diabetes mellitus
	E11.-	Type 2 diabetes mellitus
	E12.-	Diabetes mellitus associated with malnutrition
	E13.-	Other diabetes mellitus with further details
	E14.-	Other diabetes mellitus without further details
Drug prescriptions according to ATC (23)	A10A	Insulin and analogues
	A10B	Antidiabetics, excl. Insulin
Participation in disease management programme (DMP), if available	T1DMP	Participation in DMP for type 1 diabetes mellitus
	T2DMP	Participation in DMP for type 2 diabetes mellitus

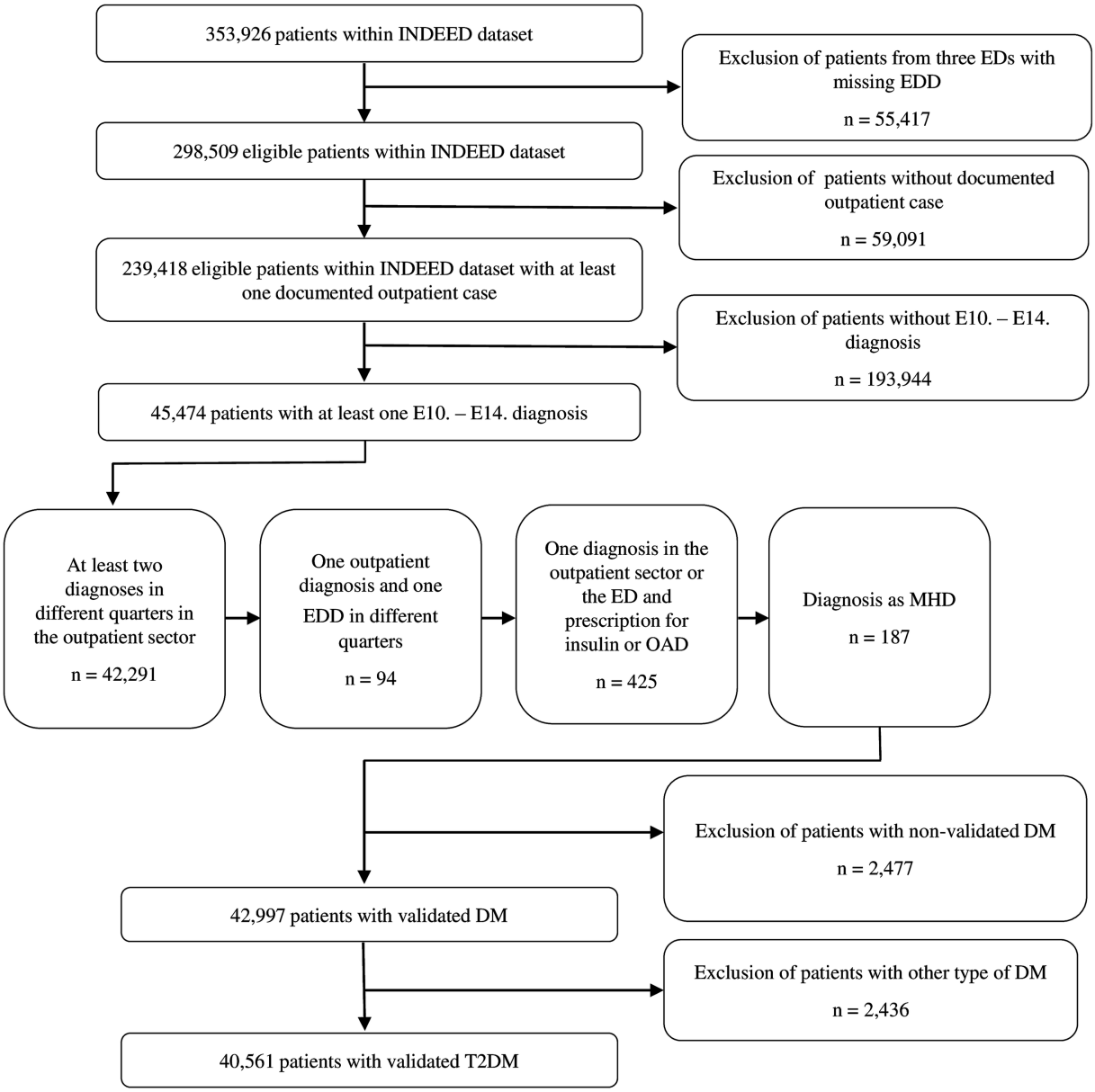


FIGURE 1
Flowchart of patient selection of all patients with validated type 2 diabetes mellitus within the INDEED dataset. DM, Diabetes mellitus; ED, Emergency department; EDD, Emergency department diagnosis; MHD, Main hospital diagnosis; OAD, Oral antidiabetic drug; T2DM, Type 2 diabetes mellitus.

coded as main hospital diagnosis in case of inpatient admission following the ED visit. The conditions were applied one after another, i.e., if condition one was fulfilled, the following conditions were not applied. Conditions one to three were defined in reference to the well-validated M2Q criterion, which describes the repeated documentation of a diagnosis over the course of a year, usually in two or more different quarters (28, 29). In deviation from the usual definition of the criterion, the presence of at least two quarters with a documented DM diagnosis or a DM-relevant drug prescription within two years, not just one year, was defined as sufficient for diagnosis validation in order to identify all cases. The quarters with DM diagnosis or prescription did not have to be consecutive, and diagnosis and prescription of antidiabetic drugs did not have to be in the same quarter. (III) Finally, the study population was further narrowed to persons with T2DM only, based on an allocation algorithm considering the presence of different combinations of E10.- to E14.- diagnoses, insulin or OAD prescriptions, and participation in a DM-specific DMP (if available, Appendix 1).

2.3 Analysis

Descriptive analyses were performed to summarise patient characteristics, health care utilisation prior to the ED visit, as well as ED diagnoses and main hospital diagnoses. Latent class analysis (LCA) was applied for population segmentation. LCA is a probabilistic, unsupervised clustering method used to determine whether unobserved homogenous subgroups (*classes*) exist within populations

based on measured indicator variables. In contrast to other clustering methods such as k-means, individuals are not assigned to a cluster by distance measures. Instead, maximum likelihood estimations, based on finite mixture modelling of assumed underlying latent classes are used to calculate probabilities of individuals belonging to all latent classes in the model (*posterior probability*). An LCA is appropriate for large study samples and categorical dependent variables (*indicator variables*) (30). It is particularly applicable for identifying subgroups that could benefit from similar interventions (31). One of the main prerequisites of LCA is the assumption of *"local independence,"* i.e., indicator variables are independent of one another. Violations of this assumption can lead to misclassification due to data redundancy and result in low accuracy of fit statistics and overestimation of the true number of classes (30).

2.3.1 Indicator variables

Table 2 describes the selected indicator variables. Age and sex represented patient demographics. The number of documented DM-related complication groups and DM-specific medication indicated the disease stage of T2DM (63). The following variables represent quality markers for T2DM outpatient care. The number of contacts with physicians in the outpatient sector characterises different levels of health care utilisation (32). Accessibility of physicians in the outpatient sector was inversely associated with PAH, although conflicting results exist (33). The differentiation of the medical specialty groups was based on the levels of the German planning scheme for the regional distribution of SHI physicians and was further restricted to disciplines relevant for T2DM patients (Appendix 3) (34). As flat rates are billed on a quarterly basis in outpatient physician care, no statement can be made regarding the actual number of physician contacts per quarter (29). All health care utilisation variables were therefore calculated on a quarterly basis. HbA1c (glycated haemoglobin) and microalbuminuria measurements, as well as ophthalmological fundus examination, are recommended as indicators for outpatient process quality in the treatment of DM (35, 36). In addition, creatinine measurement was defined as a mandatory annual measurement in the German guidelines for DMP for T2DM (37). Since microalbuminuria measurement is particularly relevant for the early detection of diabetic nephropathy and since creatinine is used as an indicator of disease progression, both indicators were considered (38). According to the German guidelines for DMP for T2DM, the HbA1c should be checked quarterly, but at least twice a year. Microalbuminuria and creatinine should be checked annually. The recommended frequency for ophthalmological fundus examination was reduced in 2015 from annually to at least biennially for people without a known risk for retinopathy (37). Regular measurements of HbA1c and microalbuminuria were shown to be negatively associated with inpatient admissions (39).

The indicators were calculated per patient. The period "one year prior to the ED visit" comprised the four quarters prior to the quarter in 2016 in which the ED visit took place. In the case of multiple ED visits per patient, the first visit was used as the calculation basis. Diagnoses, procedures, or medications were defined as not existing or not performed per patient as soon as the patient was present at least once in the outpatient data, but the corresponding billing code was not used in the defined period. Variable values were collapsed to three to four categories per indicator to ensure interpretability of the classes (31).

2.3.2 Data setup

Patterns of missing data are illustrated. Random forest imputation was conducted with ten iterations to impute missing data (40). Random forest imputation is a fully conditional, non-parametric imputation method that makes no assumptions about normality, linearity of the relation between variables, homoscedasticity, or independence (41). After imputation, collinearity between the indicator variables was checked to validate the assumption of local independence, whereas correlation coefficients under 0.50 were considered (30).

2.3.3 Model selection and validation

The selection of the number of clusters is a challenge in all segmentation methods, since universally valid latent clusters do not exist, and definitions of clusters are strongly influenced by the underlying research objective (40). To determine the number of classes, the use of various indices is recommended (42). Regarding information criteria indicating model fit, the use of the Bayesian information criterion (BIC) is recommended for large samples, with smaller values indicating better model fit (42). For very large samples, it is recommended to apply the elbow heuristic to the BIC, i.e., to find the inflection point in the BIC plot from which the decrease in values is less steep (30). To clearly identify distinct clusters, entropy-based criteria were used, with the integrated completed likelihood (ICL) proving more accurate than scaled relative entropy (42). In addition, the average silhouette width (ASW) can be used to check for within-cluster dissimilarities and cluster separation, with higher values indicating less dissimilarity (40). The ASW is usually applied in distance-based clustering methods. However, simulations have shown that model performance regarding the ASW does not differ between distance-based and probabilistic models (43). Theoretical interpretability should be considered at least as important as statistical fit values (30, 31, 42).

The selection of the final class solution was conducted in accordance with the extended selection strategy proposed by Lezhnina and Kismihók (40). The approach does not rely solely on the model fit indicated by information criteria but also considers cluster separation and partition stability. To determine the number of classes, LCA models were fitted for 1- to 10-class solutions. The selection of class solutions was then conducted under consideration of the BIC elbow heuristic, maximum ASW and minimum ICL to handle the trade-off between cluster separation and model fit (40). The smallest identified latent class in the chosen model was checked to comprise at least 5% of the study sample (31).

For internal validation, partition stability was checked via adjusted Rand index (ARI) and Jaccard index, whose values can range from zero to one and values closer to one indicate better stability (40). Furthermore, an average latent class posterior probability of at least 0.80 per class was used to assess the classification accuracy of the chosen model (31). Model selection was performed only on a proportion of the total sample, using a split ratio of 0.7 to separate training and validation data, to avoid overfitting and improve out-of-sample fit. For validation, the partition stability and classification accuracy of the chosen model were confirmed in the validation data.

2.3.4 Model interpretation

The characteristics of the classes per indicator variable as well as differences in class patterns were analyzed. The ten most frequently

TABLE 2 Description of variables used for population segmentation.

Variable	Description
Patient characteristics and stage of disease	
Sex	Sex is classified as male (1) or female (2).
Age	Age in years at the time of the ED visit in 2016. In the case of multiple ED visits in 2016 with differing ages the mean value was calculated. Age was categorised in four groups: 0–55 (1), 56–70 (2), 71–85 (3), ≥ 86 (4).
DM-related complication groups	The number of documented DM-related complication groups one year prior to the ED visit was defined based on the fourth digit of ICD-codes starting with E10 - E14 and further DM-specific codes. The following groups of complications were defined: metabolic system, eye, kidney, neuro-vascular system, multiple complications.[1] The number of documented complication groups was categorised in three groups: 0 (0), 1–2 (1), ≥ 3 (2).
T2DM specific medication	The use of DM-specific medication was estimated on drug prescriptions one year prior to the ED visit. Medication was categorised in four groups: no DM-specific medication (0), only OAD (1), only insulin (2), OAD and insulin (3).
Health care utilisation	
General practitioner visits	The number of quarters in which any billing code was claimed by a general practitioner in the year prior to the ED visit.[2] The number of quarters with contact was categorised in three groups: 0 (0), 1–2 (1), 3–4 (2).
General specialist visits	The number of quarters in which any billing code was claimed by a general specialist in the year prior to the ED visit.[2] The number of quarters with contact was categorised in three groups: 0 (0), 1–2 (1), 3–4 (2).
Specialised specialist visits	The number of quarters in which any billing code was claimed by a specialised specialist in the year prior to the ED visit.[2] The number of quarters with contact was categorised in three groups: 0 (0), 1–2 (1), 3–4 (2).
Process quality of outpatient care	
HbA1c measurement	The number of quarters in which the billing code for HbA1c measurement was claimed in the year prior to the ED visit. The number of quarters with measurement was categorised in three groups: 0 (0), 1–2 (1), 3–4 (2).
Microalbuminuria measurement	The number of quarters in which the billing code for microalbuminuria measurement was claimed in the year prior to the ED visit. The number of quarters with measurement was categorised in three groups: 0 (0), 1–2 (1), 3–4 (2).
Creatinine measurement	The number of quarters in which one of the billing codes for creatinine measurement was claimed in the year prior to the ED visit. The number of quarters with measurement was categorised in three groups: 0 (0), 1–2 (1), 3–4 (2).
Ophthalmological fundus examination	The number of quarters in which one of the billing codes for fundus examination or fluorescence angiographic examination was claimed in the year prior to the ED visit. The number of quarters with measurement was categorised in three groups: 0 (0), 1–2 (1), 3–4 (2).

ED, Emergency department; HbA1c, Glycated haemoglobin; OAD, Oral antidiabetic drugs; T2DM, Type 2 diabetes mellitus. [1]Included codes are listed in Appendix 2. Classification of complication groups based on (47). [2]Included disciplines are listed in Appendix 3. Billing codes regarding administrative activities or laboratory tests were excluded, as these billing codes do not require direct contact with a physician.

coded ED diagnoses and main hospital diagnoses per class were compared. Patient characteristics, recurrent ED visits and inpatient admissions per class were described. Recurrent ED visits and inpatient admissions were coded dichotomously. Recurrent ED visits were classified as present if there was more than one ED visit documented per patient in the participating EDs in 2016. Inpatient admission was classified as present as soon as at least one inpatient admission was documented per patient. Univariate and age-adjusted logistic regressions were performed to detect significant differences in the odds of recurrent ED visits or inpatient admissions between the classes, using the age categories described in Table 2 for age adjustment. Age was already defined as one of the discriminatory variables in the LCA, but showed little discriminatory power within the LCA (see Appendix 8). As age is known to influences both health care utilisation and disease progression, an additional model adjusted for age was created for comparison.

All steps were performed using the statistics program R version 4.3.2. The *comorbidity* index package was used to estimate the Charlson comorbidity index (44). The *missforest* package was used for the imputation of missing data (41, 45). The model selection function provided by Lezhnina and Kismihók is based on the VarSelClust function from the *VarSelLCM* package (40, 46).

2.4 Ethics and data protection

The study was approved by the ethics committee of the Charité – Universitätsmedizin Berlin (application number EA4/086/17). The data protection concept was approved by the data protection working group of the Technology and Methods Platform for Interconnected Medical Research e.V. (TMF) and the data protection officer of Charité – Universitätsmedizin Berlin (registration number 565/17/ST3). INDEED is registered in the German clinical trials registry (registration number DRKS00022969) (14).

3 Results

3.1 Study population

As shown in Figure 1, out of 239,418 eligible patients within the INDEED dataset, 40,561 patients fulfilled the inclusion criterion of having a validated diagnosis of T2DM and at least one documented outpatient case. The median age of the study population was 75 years. Almost half of the study population had severe comorbidities with CCI scores higher than four (44.3%). In 2016, a total of 56,821 visits

to the included EDs were recorded. Of the 40,561 patients with T2DM, 30,844 patients had only one recorded visit, while 9,717 had two or more. Overall, 59.0% of all visits led to inpatient admissions. At least one inpatient admission was recorded for 65.1% all patients with T2DM.

Table 3 provides additional information on the study population, categorised into patients with at least one inpatient admission and those without. This distinction is intended to show whether differences in socio-demographic factors, disease severity and the extent of outpatient care prior to the ED visit influence the need for inpatient admission.

3.2 Health care utilisation prior to the ED visit

Table 4 provides information on medical outpatient health care utilisation in the year prior to the ED visit. Although 98.5% of patients had contact with a GP, 17.8% of patients did not have their HbA1c measured during the same period.

3.3 Emergency department diagnoses and inpatient admissions

For 7,414 of the 56,821 ED visits no ED diagnoses were transmitted, affecting 6,715 patients. Among the remaining 49,407 ED visits, 110,448 diagnoses were coded, with an average of 2.4 diagnoses per ED visit. One of the 13 EDs was notably above average with 9.9 documented diagnoses per ED visit and was excluded from the following analysis of the top ten most frequently coded ED diagnoses (responding to 3,266 excluded patients accounting for 4,373 ED visits). Table 5 represents the ten most frequent ICD-codes documented in the remaining twelve EDs, considering the first three digits of the codes. It should be noted that diagnoses per patient may be coded more than once if they presented repeatedly at the ED in 2016.

For T2DM patients, who were admitted to the hospital, the inpatient mortality rate was 6.6%. Table 6 represents the ten most frequent ICD-codes documented as main hospital diagnosis in case of inpatient admission. Details on the coded T2DM diagnoses in the ED and as main hospital diagnoses in case of inpatient admission can be found in Appendix 5.

3.4 Population segmentation

3.4.1 Data setup

At 20.4%, "medication" had the highest proportion of missing data, whereas all other variables showed proportions of missing values of less than 1 % (Appendix 6). More than 99.0% of the missing medication values occurred in patients from a particular association of SHI physicians, which did not provide drug prescription data. Random forest imputation was conducted. Local independence was checked via a correlation matrix (Appendix 7). A correlation of 0.63 was found between the indicators "HbA1c" and "creatinine measurement." Therefore, "Creatinine measurement" was excluded from the LCA to avoid bias and misclassification and to reduce data redundancy (30).

3.4.2 Model selection

By applying the combination of the BIC elbow criterion and the maximum ASW indicating model fit as well as the minimum ICL to assess cluster separation, the three-class solution was selected as the final model. This is illustrated in Figure 2, which shows the ASW and BIC values for each of the 1- to 10-class solutions along the x-axis, with the minimum ICL indicated by the dash-dot vertical line.

The "number of quarters with contact with a general specialist" showed the highest discriminatory power in the three-class solution, followed by "medication" (Appendix 8). The partition stability was stable, with an ARI of 0.92 and a Jaccard index of 0.91. At exactly 0.80 for class one, the smallest average latent class posterior probability reached the target value of 0.80 (Appendix 9). Partition stability in the validation dataset was at 0.89 (ARI) and 0.87 (Jaccard). With the smallest average latent class posterior probability at 0.80, the classification accuracy was at the targeted value in the validation dataset as well.

3.4.3 Model interpretation

After model selection and validation, the model was applied to all 40,561 patients. The response distributions of the three identified classes per indicator variable are shown in Figure 3.

The first class was named *"early disease stage and high utilisation"* and represented 36.5% of the study population. Class one was characterised by low average values of indicators reflecting disease progression, with high health care utilisation. The second class, *"progressive disease stage and low utilisation,"* containing 26.1% of the study population, showed evidence of a more advanced stage of T2DM than class one, with higher values for "medication" in particular. However, compared to classes one and three, class two showed a lower utilisation of specialised care and less frequent measurement of all indicators reflecting process quality of care. The third class *"progressed disease stage and high utilisation,"* had the highest values of disease progression and health care utilisation, as well as more frequent HbA1c measurements than did the other two classes. Class three represented 37.4% of the study population.

Figure 4 illustrates the average response values per indicator and class and visualises the latent class patterns. It should be noted that classes with a high average value for one variable, for example age, may also include young people and vice versa. The data points per indicator and class should not be interpreted in isolation; instead, the different graph patterns can be compared.

Although the ICD-GM-code for T2DM (E11.-) remained among the three most frequently coded ED diagnoses and main hospital diagnoses in classes two and three, it was no longer among the top ten in class one. In all three classes, congestive heart failure and cerebral infarction were the two most frequent main hospital diagnoses (Appendix 10).

In the last step, patient characteristics and the occurrence of recurrent ED visits and inpatient admissions per class were analysed (Table 7). Overall, class three had the highest comorbidity scores, with a correspondingly high proportion of recurrent ED visits and inpatient admissions. Class one had slightly higher CCI scores than did class two, which is congruent with higher health care utilisation and a higher average age in this class. However, inpatient admissions occurred more frequently, and recurrent ED visits occurred slightly more frequently in class two than in class one.

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TABLE 3 Summary of study population characteristics.

Patient characteristics	Study population *n* = 40,561 in % (*n*)	Patients with at least one inpatient admission *n* = 26,390 in % (*n*)	Patients without inpatient admission *n* = 14,171 in % (*n*)
Age in years			
20–55	11.5 (4,674)	7.8 (2,051)	18.5 (2,623)
56–70	26.8 (10,889)	25.2 (6,658)	29.9 (4,231)
71–85	48.7 (19,757)	52.5 (13,848)	41.7 (5,909)
≥ 86 years	12.9 (5,241)	14.5 (3,833)	9.9 (1,408)
Median (IQR)	75 (64, 81)	76 (67, 82)	71 (59, 79)
Sex			
Male	50.7 (20,563)	51.9 (13,704)	48.4 (6,859)
Female	49.3 (19,998)	48.1 (12,686)	51.6 (7,312)
Insurance status			
Member	23.0 (9,345)	18.8 (4,951)	31.0 (4,394)
Family insured	2.6 (1,071)	2.1 (542)	3.7 (529)
Retiree	74.3 (30,145)	79.2 (20,897)	65.3 (9,248)
Charlson comorbidity index[1]			
CCI Score 0	0.9 (379)	1.0 (255)	0.9 (124)
CCI Score 1–2	25.6 (10,369)	21.6 (5,708)	32.9 (4,661)
CCI Score 3–4	29.2 (11,852)	28.5 (7,518)	30.6 (4,334)
CCI Score ≥ 5	44.3 (17,959)	48.9 (12,908)	35.6 (5,051)
No outpatient diagnoses documented	<0.1 (2)	<0.1 (1)	<0.1 (1)
Median (IQR)	4 (2, 6)	4 (3, 6)	3 (2, 5)
Presence of DM-related complications[2]			
0 complication groups	51.9 (21,055)	49.3 (13,008)	56.8 (8,047)
1–2 complication groups	44.3 (17,976)	46.5 (12,261)	40.3 (5,715)
≥ 3 complications groups	3.8 (1,528)	4.2 (1,120)	2.9 (408)
No outpatient diagnoses documented	<0.1 (2)	<0.1 (1)	<0.1 (1)
Frequency of ED presentation in 2016[3]			
1–2 presentations/year	91.9 (37,288)	89.0 (23,495)	97.3 (13,793)
3–9 presentations/year	8.0 (3,226)	10.8 (2,854)	2.6 (372)
≥ 10 presentations/year	0.1 (47)	0.2 (41)	<0.1 (6)

CCI, Charlson comorbidity index; IQR, Interquartile range; ED, Emergency department; DM, Diabetes mellitus. [1]According to Appendix 4, based on (44, 60); calculation basis: outpatient data one year prior to ED visit. [2]According to Appendix 2; based on (47); calculation basis: outpatient data one year prior to ED visit. [3]Categorisation according to (61); regarding visits in included EDs.

Logistic regression revealed increasing odds of inpatient admissions with increasing average disease stage of T2DM per class (Table 8). The effect can already be seen between classes one and two, although class one had higher values in general comorbidity than class two. Differences were particularly visible in the age-adjusted model, in which the chance of inpatient admission in class two was even higher than that in class three.

4 Discussion

4.1 Type II diabetes mellitus patients attending emergency departments

This study was the first to assess the diagnoses of T2DM patients in EDs in Germany using cross-sectoral claims data. With a median age of 75 years, the T2DM study population was older than the underlying ED cohort (25). As the dataset comprised individuals who had visited the ED at least once, it can be assumed that the individuals in the study population were older and at a more advanced stage of the disease compared to all T2DM patients in the general population (47). Additionally, it was already known that the application of the M2Q criterion particularly excludes younger individuals in the early stages of disease (28).

GP utilisation in the year prior to the ED visit was high, 98% of the T2DM patients had contact with a GP at least once in the first two quarters prior to the ED visit. However, for 17.8% of patients, no HbA1c measurement was billed in the year prior to the ED visit. This percentage was considerably higher than the proportion of 4.3% of T2DM patients aged 45 years and older without HbA1c measurements in the last twelve months reported by the National Diabetes Surveillance in Germany for 2021 (48, 49). Similarly, only

TABLE 4 Outpatient health care utilisation one year prior to the index emergency department visit in 2016.

Patient-based characteristics	Study population *n* = 40,561 in % (*n*)	Patients with at least one inpatient admission *n* = 26,390 in % (*n*)	Patients without inpatient admission *n* = 14,171 in % (*n*)
Medication for DM			
No DM-specific medication	29.6 (12,025)	29.2 (7,715)	30.4 (4,310)
OAD only	26.4 (10,710)	26.2 (6,922)	26.7 (3,788)
Insulin only	10.2 (4,151)	12.2 (3,223)	6.5 (928)
Insulin and OAD	13.3 (5,392)	14.6 (3,855)	10.8 (1,537)
No drug prescription documented	20.4 (8,283)	17.7 (4,675)	25.5 (3,608)
Number of quarters with documented			
Contact to a general practitioner			
0 quarters/ year	1.7 (701)	1.9 (513)	1.3 (188)
1–2 quarters/ year	3.6 (1,473)	3.2 (843)	4.4 (630)
3–4 quarters/ year	94.6 (38,387)	94.9 (25,034)	94.2 (13,353)
Contact to a general specialist			
0 quarters/ year	17.7 (7,185)	18.9 (4,986)	15.5 (2,199)
1–2 quarters/ year	28.8 (11,671)	28.9 (7,620)	28.6 (4,051)
3–4 quarters/ year	53.5 (21,705)	52.2 (13,784)	55.9 (7,921)
Contact to a specialised specialist			
0 quarters/ year	42.9 (17,387)	43.4 (11,493)	41.6 (5,894)
1–2 quarters/ year	38.9 (15,761)	37.8 (9,965)	40.9 (5,796)
3–4 quarters/ year	18.3 (7,413)	18.7 (4,932)	17.5 (2,481)
HbA1c measurement			
0 quarters/ year	17.8 (7,231)	18.1 (4,778)	17.3 (2,453)
1–2 quarters/ year	33.3 (13,489)	32.6 (8,616)	34.4 (4,873)
3–4 quarters/ year	48.9 (19,841)	49.2 (12,996)	48.3 (6,845)
Microalbuminuria measurement			
0 quarters/ year	84.3 (34,185)	84.3 (22,237)	84.3 (11,948)
1–2 quarters/ year	13.8 (5,607)	13.9 (3,677)	13.6 (1,930)
3–4 quarters/ year	1.9 (769)	1.8 (476)	2.1 (293)
Creatinine measurement			
0 quarters/ year	12.8 (5,174)	13.9 (3,419)	12.4 (1,755)
1–2 quarters/ year	42.4 (17,196)	41.1 (10,844)	44.8 (6,352)
3–4 quarters/ year	44.8 (18,191)	45.9 (12,127)	42.8 (6,064)
Ophthalmological fundus examination			
0 quarters/ year	67.0 (27,162)	68.0 (17,952)	65.0 (9,210)
1–2 quarters/ year	30.0 (12,174)	29.0 (7,657)	31.9 (4,517)
3–4 quarters/ year	3.0 (1,225)	3.0 (781)	3.1 (444)

ED, Emergency department; DM, Diabetes mellitus, HbA1c, Glycated haemoglobin; OAD, Oral antidiabetic drug.

one third (33.0%) of patients in the study population had an ophthalmological fundus examination in the year before the ED visit, whereas the proportion of T2DM patients with an eye examination in the last 12 months was 64.8%, as reported by the National Diabetes Surveillance in Germany for T2DM patients aged 45 years and older in 2021 (48). When comparing the data, it should be noted that the Diabetes Surveillance data are based on self-report survey data, not claims data (48). In addition, temporal changes between 2016 and 2021 may have contributed to the differences, although there were indications that health care utilisation for specialised care of T2DM patients decreased rather than increased in 2020 due to the starting COVID-19 pandemic (50, 51). Furthermore, the German guideline for DM treatment was adapted in 2015, as part of which the recommended period for eye examinations for people without known risk for retinopathy was adjusted from annually to biennial. This may have contributed to a

TABLE 5 Top ten coded three-digit ICD-10-codes in the emergency department.

ICD-code	ICD-code description	Number of ICD-codes documented n = 67,196 in % (n)
I10	Essential (primary) hypertension	2.5 (1,679)
E11	Type 2 diabetes mellitus	2.1 (1,398)
M54	Back pain	1.7 (1,172)
S00	Superficial injury to the head	1.7 (1,138)
I63	Cerebral infarction	1.7 (1,115)
R10	Abdominal and pelvic pain	1.7 (1,112)
J18	Pneumonia, pathogen not specified	1.6 (1,103)
I50	Congestive heart failure	1.6 (1,046)
R07	Throat and chest pain	1.5 (1,009)
I48	Atrial fibrillation and flutter	1.5 (978)
	Total share of the 10 most frequent codes	17.6%

TABLE 6 Top ten coded three-digit ICD-10-codes as main hospital diagnosis in case of inpatient admission.

ICD-code	ICD-code description	Number of ICD-codes documented n = 33,224 in % (n)
I63	Cerebral infarction	6.1 (2,032)
I50	Congestive heart failure	5.4 (1,784)
E11	Type 2 diabetes mellitus	3.1 (1,043)
S06	Intracranial injury	3.0 (1,004)
I21	Acute myocardial infarction	2.9 (957)
A41	Other sepsis	2.8 (943)
J18	Pneumonia, pathogen not specified	2.1 (714)
G45	Cerebral transient ischaemia and related syndromes	2.1 (706)
N17	Acute renal failure	2.1 (687)
J44	Other chronic obstructive pulmonary disease	2.0 (663)
	Total share of the 10 most frequent codes	31.6%

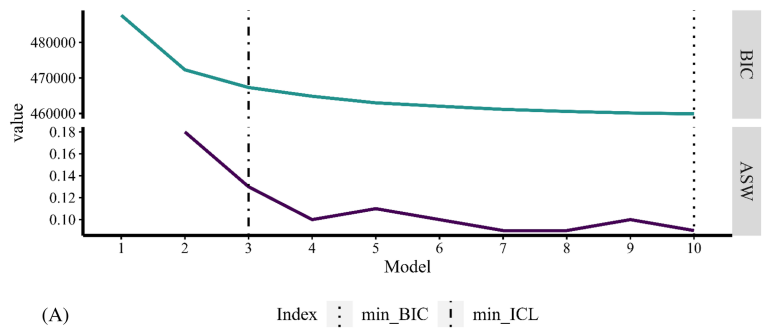
reduced number of check-ups in the period under review in this study (52). Overall, 84.3% of patients in the study population did not have a microalbuminuria measurement billed in the year prior to the ED visit, but billing codes for creatinine measurement were documented for 87.2%. Similar results on creatinine measurement were reported for patients participating in the DMP for T2DM from the German federal state of North Rhine-Westphalia, ranging from 85.6 to 95.6% between 2014 and 2016 (53).

The proportion of ED visits for T2DM patients admitted as inpatients (59.0%) was notably higher than the proportion of patient visits admitted as inpatients (42.8%) in the underlying ED cohort, which is consistent with previous research (12, 25). Patients with at least one inpatient admission were on average at a more advanced stage of DM with more comorbidities than patients who were treated exclusively as outpatients. Inpatient mortality (6.6%) was about one third higher in the study population than in the underlying cohort (4.3%) (25). T2DM was the second most frequent coded ED diagnosis, as well as the third most frequent main hospital diagnosis in cases of subsequent inpatient admission. In addition, there are several diseases coded under the most frequent ED diagnoses or main hospital diagnoses that can be promoted by DM or similar risk factors as DM, such as hypertension, kidney diseases and cardiovascular diseases. Particularly striking is the high frequency of cardiovascular diagnoses, which emphasises the need for guideline-compliant check-ups for secondary diseases and consistent glycaemic control to avoid microvascular damage (37). Due to the advanced age and high comorbidity in the study population, it should be noted that presumably not all cases defined as having PAH by diagnosis were preventable in the outpatient sector, as health status as well as lifestyle-related factors not represented in the dataset are known as confounders of the relationship between access to primary care and PAH (54).

4.2 Segmentation of T2DM patients prior to an ED visit

Using data-driven segmentation methods, three classes differing in terms of DM-disease progression and health care utilisation were identified. It should be noted, that the labels given to the classes describe only average characteristics of the group, not on every individual person in the respective group (*"naming fallacy,"* (31)). For example, there might be few individuals in class one, *"early disease stage and high utilisation,"* with a progressed stage of T2DM, who were assigned to that class due to other characteristics like age or health care utilisation. Furthermore, the assignment of individuals to the classes was based on the information documented in the dataset. It is possible that some individuals in class one were already at a progressed stage of T2DM prior to their ED visit, despite having no visible symptoms or documented diagnoses. The LCA revealed that the variables "number of quarters with contact with a general specialist," "medication" and "complications" differed across the identified classes (Figure 3; Appendix 8). This indicates that both disease progression and specialist utilisation are important for interpreting the patient groups. These findings highlight the potential for developing targeted care strategies in integrated care settings.

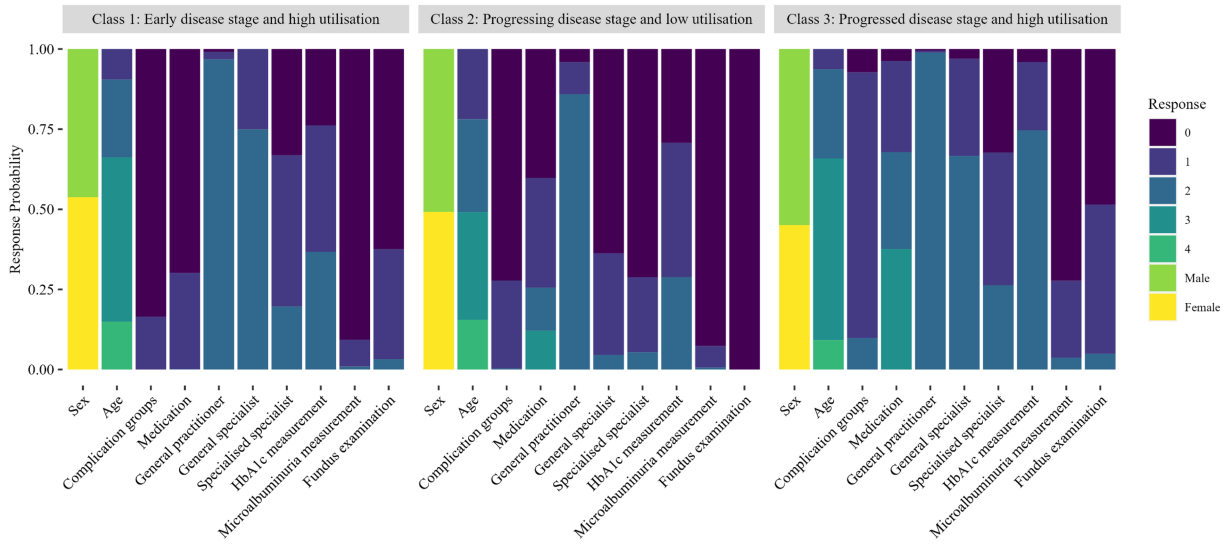
On average, the indicators used to measure the progression of T2DM showed an early stage of disease in the first class. However, since the CCI scores indicated a pronounced level of comorbidity, it can be assumed that this class would benefit from preventive measures targeting risk factors promoting a range of non-communicable diseases. In contrast, class two showed on average an advanced disease stage of T2DM and at the same time the lowest CCI values. Beyond the prevention of primary risk factors, the focus for this group should be on secondary prevention of T2DM in the form of reducing disease progression and associated complications. In both class one and class two, the recommended frequency of quarterly HbA1c measurements was met by only approximately one third of patients in the respective classes. This indicates a high potential for improving process quality in the



(B)

Model	BIC	ICL	ASW
1	487663.99	-243831.28	NA
2	472295.54	-239522.95	0.18
3	**467321.66**	**-237971.32**	**0.13**
4	464853.15	-238213.43	0.10
5	462994.99	-238201.68	0.11
6	462051.62	-238748.91	0.10
7	461156.38	-238128.09	0.09
8	460583.46	-239134.80	0.09
9	460138.27	-238468.78	0.10
10	459902.72	-239239.50	0.09

FIGURE 2
Visualisation of 1- to 10-class solutions **(A)** and cluster selection results **(B)** assessed for the latent class analysis. The model name shown on the x-axis indicates the number of clusters tested for the respective model.



For further information on the response values per indicator variable s. Table 2

FIGURE 3
Response probability per indicator per class identified with the latent class analysis.

outpatient care sector in both classes (48). For class three, a high overall morbidity regarding T2DM as well as other diseases could be shown. For this group, the focus should be on ensuring continuity of care and thus on avoiding disruptions of care. Instruments of managed care, e.g., DMPs, GP-centred gatekeeping or case management by home-nursing units, offer a promising approach to both reducing emergency cases and ensuring better cross-sectoral continuity of care in cases of unavoidable ED visits or inpatient admissions (55). For clinicians in the outpatient setting, access to information on patients' participation in regular check-ups, existing specialist care, and any complications related to T2DM is essential. This information enables the clinician to more accurately assess their patients' condition and adapt their treatment accordingly. Guideline-based treatment has the potential to prevent the disease from progressing and thus reduce the risk for emergency treatment.

Regarding PAH, the ten most frequently coded main hospital diagnoses per class suggest that in classes two and three PAH occurred more often directly due to T2DM, among other causes, while T2DM had more of an indirect effect on the occurrence of PAH in class one. Beyond that, it could be confirmed that the risk of inpatient admission increased in classes with an average advanced stage of T2DM (12). In comparison, class two with a less pronounced CCI but more advanced T2DM even had a higher risk for inpatient admissions than class one with a slightly more pronounced average CCI but less pronounced T2DM. The higher chance of inpatient admission in class two than in class three was more visible in the age-adjusted model than in the crude model, however, this finding must be interpreted with caution, as age was already included as an indicator variable in class partitioning. Further research is necessary to specify the health care needs of the identified classes in detail to plan and evaluate strategies that can reduce the proportion of PAH patient cases.

From a methodological perspective, the combination of values assessing model fit and values assessing cluster separation ensured interpretability (40). The graphs running parallel in some sections in Figure 4 suggest that the so-called salsa effect may have occurred in

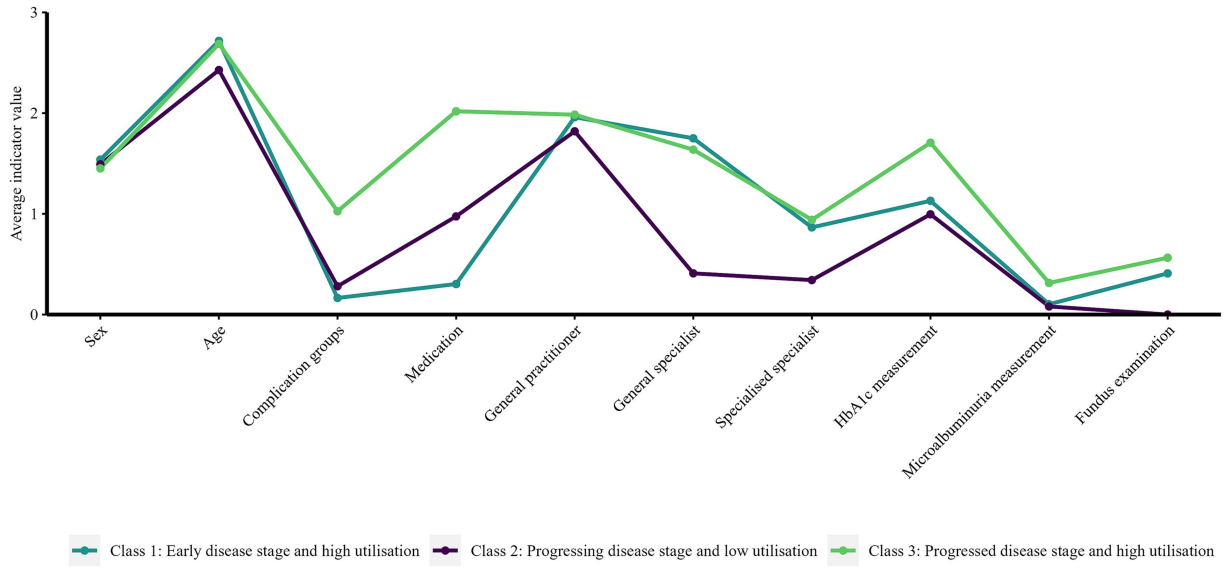


FIGURE 4
Average response values per indicator variable per class identified with the latent class analysis.

the analysis. This effect describes the phenomenon in which different patterns were not identified, but rather the same pattern in varying degrees of severity [*"mild, medium and hot salsa,"* (30)]. This phenomenon does not necessarily represent a methodological error but must be considered in interpreting the classes (31). The occurrence of the salsa effect was accepted for this study since interactions between disease stages and health care utilisation contribute to the understanding of disease trajectories and health care needs. The slight salsa effect, particularly between the variables of health care utilisation and process quality, can be explained by the fact that no examination would have taken place without prior contact with the responsible physician and that two variables indicating disease progression were included in the model for class partitioning. It can be assumed that the effect would have been smaller if other indicator variables had been included that reflect not only the utilisation of services provided by physicians but also of other professions, such as outpatient home nursing, podiatry, nutrition assistants or specialised outpatient wound care. In addition to other health care levels, further studies should consider class differences in terms of socioeconomic status, lifestyle-related factors, physician density or living in a deprived environment, which are already known to be associated with the utilisation of health care services and the occurrence of PAH (54, 56).

4.3 Potential limitations

The dataset offered the opportunity to map cross-sectoral health care utilisation via the ED as an interface between the inpatient and outpatient sectors. However, several limitations have to be mentioned. First, providers in the outpatient sector show different coding practices due to low-standardised coding guidelines (29, 57). Second, due to the structure of the dataset and the quality of coding diagnoses in EDs in Germany, it was not clear whether DM, if coded as a diagnosis in the ED, was the main cause for the ED visit or whether it was coded as a concomitant disease. The lack of differentiation between principal and secondary diagnoses in the ED dataset was one of the main limitations of the dataset and highlights well-known challenges of data quality in the German outpatient sector (57). This limitation does not apply for the main hospital diagnoses, as only one main hospital diagnosis was documented per inpatient case. Since T2DM and several diseases that are secondary to T2DM were among the top ten inpatient diagnoses, we assume that in many cases DM contributed at least in part to the need for the ED visit.

Third, the lack of complete data on DMP participation in the underlying dataset represented a further limitation and hinders the evaluation of an already well-implemented programme (1, 58, 59). If insights had been available to determine whether a large proportion of T2DM patients were not enrolled in a DMP, this would have clearly highlighted the need to promote participation in such programmes. Fourth, the lack of data on drug prescriptions from one of the participating associations of SHI physicians may have led to the exclusion of T2DM patients from the study population due to the applied criteria for diagnosis validation. Fifth, in addition, the outpatient claims data do not contain any quantitative clinical data, for example on the level of measured HbA1c or other laboratory parameters. Sixth, no lifestyle-related information, for example on physical activity, dietary behaviour or social support as well as socioeconomic status was available to evaluate their association with T2DM healthcare provision in Germany. Socioeconomic and lifestyle-related factors as well as HbA1c levels have already been shown to be relevant factors when segmenting T2DM patients into subgroups (17). This information could have contributed to practical recommendations for improving the quality of outpatient care – such as not only regularly measuring HbA1c, but also adjusting treatment regimens when values fall outside the target range. Further research is necessary to develop data driven recommendations.

Seventh, since not all associations of SHI physicians in Germany transmitted outpatient data, the ED patients may have had contact

TABLE 7 Patient characteristics and occurrence of recurrent emergency department visits and inpatient admission per class identified by the latent class analysis.

Patient characteristics	Class 1 *n* = 14,797 in % (*n*)	Class 2 *n* = 10,579 in % (*n*)	Class 3 *n* = 15,185 in % (*n*)
Age in years			
20–55	9.5 (1,401)	21.8 (2,307)	6.4 (966)
56–70	24.3 (3,595)	29.1 (3,075)	27.8 (4,219)
71–85	51.4 (7,605)	33.6 (3,556)	56.6 (8,596)
≥ 86	14.9 (2,196)	15.5 (1,641)	9.2 (1,404)
Median (IQR)	76 (66, 82)	70 (58, 81)	75 (67, 81)
Sex			
Male	46.2 (6,836)	50.9 (5,380)	55.0 (8,347)
Female	53.8 (7,961)	49.1 (5,199)	45.0 (6,838)
Charlson comorbidity index[1]			
CCI Score 0	0.5 (70)	2.9 (309)	0
CCI Score 1–2	31.5 (4,655)	38.5 (4,072)	10.8 (1,642)
CCI Score 3–4	31.3 (4,634)	28.8 (3,048)	27.5 (4,170)
CCI Score ≥ 5	36.8 (5,438)	29.8 (3,148)	61.7 (9,373)
No outpatient diagnoses documented	0	<0.1 (2)	0
Median (IQR)	4 (2, 5)	3 (2, 5)	5 (4, 7)
Presence of DM-related complications[2]			
0 complication groups	83.2 (12,309)	72.3 (7,644)	7.3 (1,102)
1–2 complication groups	16.8 (2,488)	27.4 (2,901)	82.9 (12,587)
≥ 3 complications groups	0	0.3 (32)	9.9 (1,496)
No outpatient diagnoses documented	0	<0.1 (2)	0
Recurrent ED visits			
No	77.3 (11,435)	76.7 (8,116)	74.4 (11,293)
Yes	22.7 (3,362)	23.3 (2,463)	25.6 (3,892)
Inpatient admission			
No	39.2 (5,795)	33.6 (3,556)	31.7 (4,820)
Yes	60.8 (9,002)	66.4 (7,023)	68.3 (10,365)

CCI, Charlson comorbidity index, ED, Emergency department, IQR, Interquartile range; DM, Diabetes mellitus. [1]According to Appendix 4, based on (44, 60); calculation basis: outpatient data one year prior to ED visit. [2]According to Appendix 2; based on (47); calculation basis: outpatient data one year prior to ED visit.

with a physician billed through one of the associations of SHI physicians not represented in the dataset. Therefore, it was not possible to distinguish whether individuals who did not appear in the outpatient data prior to the ED visit have never had contact with a physician or have had a physician contact that was billed via an association of SHI physicians not included in the study and thus not transmitted to the study site. In addition, no information is known about ED visits or inpatient admissions before 2016 or visits to EDs that are not part of the INDEED study or the utilisation of services that are not covered by the SHI, i.e., have to be paid out of pocket. The dataset therefore did not allow us to draw conclusions about total lack of access to health care prior to the ED visit or first-time diagnoses in the ED. Identification of first-time diagnoses of DM in the ED was additionally prevented by the application of the M2Q criterion for diagnosis validation, as individuals without at least one outpatient diagnosis or DM-medication use prior to the ED visit or DM as the main hospital diagnosis were excluded from the study population.

Eighth, it should be noted that the available data and period under consideration did not allow us to draw conclusions on any causal inference between health care utilisation and disease stage. For example, no conclusions can be drawn as to whether low health care utilisation occurred due to a lack of need in the case of low morbidity, or whether low morbidity occurred due to the lack of documented diagnoses due to low utilisation.

5 Conclusion

The results of the indicators measuring the frequency of medical examinations recommended by guidelines suggest the potential for improving process quality in the outpatient sector to prevent ED utilisation. Our study showed that segmenting the T2DM population according to their health care utilisation contributes to a better understanding of cross-sectoral patterns of care. We identified three

TABLE 8 Logistic regression comparing occurrence of recurrent emergency department visits and inpatient admissions per class.

Compared outcome	Univariate regression		Age-adjusted regression	
	OR	[CI]	OR	[CI]
Recurrent ED visits				
Class 1: Early disease stage and high utilisation	1		1	
Class 2: Progressive disease stage and low utilisation	1.03	[0.97; 1.10]	**1.07**	[1.01; 1.13]
Class 3: Progressed disease stage and high utilisation	**1.17**	[1.11; 1.24]	**1.18**	[1.12; 1.24]
Inpatient admission				
Class 1: Early disease stage and high utilisation	1		1	
Class 2: Progressive disease stage and low utilisation	**1.27**	[1.21; 1.34]	**1.48**	[1.40; 1.56]
Class 3: Progressed disease stage and high utilisation	**1.38**	[1.32; 1.45]	**1.41**	[1.34; 1.48]

CI: 95%, Confidence interval; OR, Odds ratio; ED, Emergency department. Letters in bold indicate $p < 0.05$.

latent classes of T2DM characterised as *"early disease stage and high utilisation"* (36.5% of the study population), "*progressing disease stage and low utilisation*" (26.1%) and *"progressed disease stage and high utilisation"* (37.4%). This can contribute to plan and establish health care measures aimed at reducing PAH and to improve health care continuity. Nevertheless, further research is necessary to identify and evaluate respective interventions per identified class. In addition, further research should investigate the role of non-physician health care providers as well as socioeconomic and lifestyle-related factors in cross-sectoral care patterns.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: due to the high sensitivity of the data in the project, it is not possible to make those available to the public. In the central data management of the project the data are already pseudonymised twice. Data are made available exclusively to the analyzing partners of the consortium in anonymised form and only with variables that are matched to the research question. Requests to access these datasets should be directed to antje.fischer-rosinsky@charite.de.

Ethics statement

The studies involving humans were approved by Ethics committee of the Charité – Universitätsmedizin Berlin (application number EA4/086/17). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

Author contributions

MR: Conceptualization, Data curation, Formal analysis, Methodology, Software, Writing – original draft, Writing – review & editing. AC: Methodology, Software, Validation, Writing – review & editing. YW: Data curation, Methodology, Supervision, Writing – review & editing. AF-R: Methodology, Project administration, Supervision, Writing – review & editing. AS: Methodology, Project administration, Supervision, Writing – review & editing. DR: Methodology, Supervision, Writing – review & editing. MM: Project administration, Supervision, Writing – review & editing. TK: Project administration, Supervision, Writing – review & editing. LR: Conceptualization, Methodology, Software, Supervision, Validation, Writing – review & editing. CH: Conceptualization, Methodology, Resources, Software, Supervision, Validation, Writing – review & editing.

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Conflict of interest

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Generative AI statement

The authors declare that Gen AI was used in the creation of this manuscript. ChatGPT was used as a tool for debugging R code and to specify R functions.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmed.2025.1509220/full#supplementary-material

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Will centralized drug procurement policy improve enterprises' total factor productivity?

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Against the backdrop of China's healthcare reform challenges in drug pricing, this study investigates the impact of the National Centralized Drug Procurement (NCDP) policy implemented in 2018. Employing Difference-in-Differences (DID) methodology on quarterly data from A-share listed pharmaceutical firms (2003-2021, sourced from WIND/CSMAR databases), we demonstrate that NCDP participation significantly reduces Total Factor Productivity . Robustness is confirmed through index substitution, propensity score matching, and lag tests. The negative effect is amplified in non-state-owned enterprises, non-TCM manufacturers, and firms with high analyst coverage. Mechanistically, NCDP suppresses TFP through: (i) tightened financing constraints (↑KZ index) impairing capital allocation efficiency, and (ii) an indirect pathway where short-term R&D surges (↑RD) trigger resource crowding-out effects, compounded by diminished investment efficiency (↑INV), ultimately forming an "R&D→investment inefficiency→TFP↓" transmission chain. To reconcile public welfare objectives with corporate sustainability, we propose dual optimization strategies: *differentiated financing support* and *innovation incentive reform*. These establish a sustainable equilibrium between price control and TFP enhancement, providing actionable solutions for nationwide NCDP scaling.

KEYWORDS

national centralized drug procurement, listed drug manufacturing enterprises, healthcare policy reform, financing constraints, total factor productivity

1 Introduction

Excessively inflated drug prices have long been a persistent issue in China's healthcare reform. Despite ongoing policy efforts to reduce residents' medical expenses, the results have been minimally effective. The primary reason is that these policies fail to address the strategies used by hospitals and pharmaceutical companies to circumvent and undermine their effects, leading to limited success in lowering drug prices. Consequently, problems such as "decoupling of quantity and price," "fragmented procurement," and "financing medical services through drug sales" remain unresolved. To address these issues, relevant authorities have gradually implemented the National Centralized Drug Procurement (NCDP) reform.

The NCDP policy, administered by the National Healthcare Security Administration (NHSA), seeks to substantially lower drug procurement costs by requiring designated medical institutions to allocate most of their purchase volumes to winning bidders. This approach, based on the principles of "volume-for-price exchange" and "quantity-price linkage," imposes dual pressures on pharmaceutical manufacturers by simultaneously affecting product pricing and production volumes. As the policy undergoes further refinement, systematically examining its actual impact on the Total Factor Productivity (TFP) of pharmaceutical firms is crucial for evaluating its effectiveness and informing institutional design improvements.

Adopting a corporate finance perspective, this study explores how NCDP affects firm-level TFP and proposes institutional improvements to support collaborative governance under the NCDP framework.

Existing research on NCDP has primarily examined its effects on price control. Empirical evidence confirms that the policy significantly reduces the prices of drugs listed in the procurement catalog, with the extent of price suppression negatively correlated with market concentration (1–4). However, the micro-level mechanisms through which NCDP influences pharmaceutical firms remain insufficiently explored. As an institutional innovation in public procurement, NCDP aligns with demand-side industrial policy tools (5), offering a theoretical framework for analyzing its firm-level effects. TFP, a core indicator of high-quality enterprise development, serves as a key mechanism through which industrial policy promotes economic transformation and upgrading. This study empirically examines the impact of NCDP on enterprise TFP using microdata from pharmaceutical manufacturers, aiming to uncover how demand-side industrial policies influence corporate performance and productivity.

To address these questions, the study employs quarterly data from China's A-share listed pharmaceutical manufacturing firms between 2003 and 2021. A multi-period difference-in-differences (DID) approach is used to assess the causal impact of NCDP on TFP. Additionally, the study investigates heterogeneity in NCDP's effects across firms with different characteristics and explores the transmission mechanisms through which the policy influences firm productivity.

This study makes three key contributions. First, it expands the understanding of NCDP's microeconomic effects by focusing on enterprise TFP, providing empirical evidence on how centralized procurement participation shapes firm productivity. Second, by leveraging the capital market's resource allocation functions, it identifies specific mechanisms—such as heightened financing constraints, increased innovation investment, and reduced investment efficiency—through which NCDP affects productivity, revealing chain-mediated mechanisms that enhance understanding of the interaction between macro-level regulation and micro-level corporate efficiency. Third, the study analyzes heterogeneous effects based on ownership structure, product type, and analyst coverage, offering practical insights for refining healthcare market reforms, optimizing policy design, and improving enterprise TFP, thereby supporting evidence-based policymaking and collaborative implementation under the NCDP framework.

2 Policy background, research status, and research hypotheses

2.1 Institutional background of NCDP

NCDP is a reform led by the NHSA where the bidding department commits to allocating most of the procurement share from designated medical institutions to the winning companies. This approach aims to reduce drug prices by leveraging bulk purchasing. The concepts of "exchanging volume for price" and "linking quantity with price" reflect this strategy. By consolidating demand from multiple provinces and cities, a "joint procurement office" is established to implement the NCDP on behalf of public medical institutions. The procurement process starts with selecting NCDP drugs. Government departments then collate drug demand from medical institutions and determine the planned NCDP volume. Based on this, the Medical Insurance Bureau meets with pharmaceutical companies to attract bids and eventually announces the volume-based procurement plan (6).

Since 2015, China has introduced successive drug procurement policies such as the "Opinions on Further Regulating the NCDP Work of Medical Institutions" and the "Guidance on Improving the NCDP Work of Public Hospitals," aiming to coordinate the reform of drug procurement processes and bidding methods. Through the principle of "linking quantity and price" and competitive bidding, the NCDP establishes prices by exchanging quantity for price.

The primary distinction between NCDP and previous bidding procurements is that NCDP announcements commit winning enterprises to procure the majority share of specified drug types. Drugs not included in NCDP can still be procured through regular bidding, but their market share is reduced. Higher procurement volumes incentivize pharmaceutical companies to lower bid prices, facilitating quantity-for-price exchange. Moreover, after signing contracts, hospitals swiftly execute procurement plans to avoid penalties. The Medical Insurance Bureau oversees drug procurement, minimizing hospitals' opportunities for secondary price negotiations and kickbacks. By adhering to NCDP volume commitments, drug procurement costs are effectively reduced.

In January 2021, the State Council issued the "Opinions on Promoting the Normalization and Institutionalization of NCDP Work" (referred to as the "opinions" hereafter). These "opinions" advocate for enhancing a market-led drug price formation mechanism, harnessing the strategic purchasing power of the medical insurance fund, and advancing the normalization and institutionalization of NCDP initiatives. The objective is to establish a governmental organizational framework, alliance procurement strategies, and platform operations, accelerating the establishment of a unified and accessible NCDP market nationwide. This aims to guide drug prices towards reasonable levels, significantly alleviate the financial burden of medications on the public, foster healthy growth in the pharmaceutical sector, drive reforms in public medical institutions, and ensure equitable access to essential healthcare services.

Regarding NCDP categories, the emphasis is on including drugs from the basic medical insurance drug catalog that are essential for clinical needs and have high usage and procurement costs. The objective is to progressively encompass all domestically listed drugs that are clinically necessary and of reliable quality, achieving comprehensive procurement. Priority is given to drugs that have undergone (or are deemed to have undergone) consistency evaluation for generic drug quality and efficacy (referred to as "consistency evaluation").

Regarding procurement rules, the agreed procurement ratio is determined reasonably based on the drug's clinical usage characteristics, market competition patterns, and the number of selected enterprises. This ratio is maximized under the premise of ensuring quality, maintaining supply, and preventing monopolies. The selection of enterprises is based on market competition and supply capacity, emphasizing scale effects and fostering effective competition. Participation by enterprises is voluntary, with independent quoting. Selections are made through competition on quality and price. The outcomes reflect the principle of linking quantity and price, clearly defining the agreed procurement volumes for each selected enterprise.

To manage the NCDP budget effectively, a prepayment mechanism is established where the medical insurance fund pre-pays

no less than 30% of the annual agreed procurement amount to medical institutions. As institutions progress in procurement, this prepayment is gradually offset against medical expenses claimed.

To date, NCDP has successfully conducted eight rounds of bidding activities covering over 300 drug categories.

NCDP becomes increasingly standardized and institutionalized, it has disrupted the non-equilibrium structure of the government pricing model, allowing multiple entities to participate more comprehensively in the entire drug pricing process under established rules. NCDP, functioning as a government procurement strategy, essentially operates as a demand-side industrial policy tool. However, its notable distinction from previous demand-side industrial policy tools lies in its additional conditions, which set product prices significantly below prevailing market levels while requiring substantial product supply. Therefore, NCDP drug pricing itself represents a distinctive form of demand-side industrial policy.

Pharmaceutical manufacturing companies, as market participants, are inevitably influenced by both the combined impacts of product prices and production volumes. As policies progressively refine, the effects on these companies necessitate thorough investigation. Therefore, this paper explores the actual impact of NCDP on firms' TFP from a corporate finance perspective. We propose institutional improvements aimed at fostering a cooperative and mutually beneficial outcome for all stakeholders within the NCDP framework.

2.2 Industrial policy and TFP

Kenneth Arrow and Gérard Debreu's General Equilibrium Theory provides a foundational framework for analyzing interactions among market variables within economic systems. Within this framework, market prices for all goods and services are endogenously determined through supply and demand interactions, leading to optimal resource allocation and market equilibrium. When the government imposes price ceilings below market equilibrium and engages in large-scale procurement, these artificial controls disrupt normal supply–demand dynamics and result in price distortions.

Under the NCDP policy, the government functions as the primary buyer, with procurement expenditures directly flowing to enterprises. This mechanism directly influences firms' production, operations, and investment decisions, and ultimately impacts their production efficiency. By setting prices below market equilibrium and implementing bulk procurement, the NCDP policy results in three primary efficiency losses: first, distorted price signals hinder efficient resource allocation and suppress corporate innovation (7); second, non-competitive procurement leads to adverse selection, enabling inefficient firms to obtain contracts via rent-seeking, which results in crowding-out effects (8, 9); third, excessive reliance on procurement orders reduces market adaptability—evidence from Chinese enterprise data indicates that a 1% increase in government procurement share leads to a 0.5% decline in TFP (10). Nakabayashi (11) further shows that preferential procurement policies substantially raise transaction costs and diminish market efficiency.

From a demand-side industrial policy perspective, the NCDP theoretically generates a "demand-pull" effect that could stimulate corporate innovation (12). However, empirical findings are mixed: Aghion et al. (13) report that competition-enhancing policies increase TFP, whereas Qian et al. (14) find that the Ten Key Industry Revitalization Plans reduced firm productivity. Zhang et al. (15) also demonstrate that targeted industrial policies inhibit TFP growth, while inclusive policies facilitate more efficient resource allocation (16). This divergence arises from variations in policy instruments—NCDP, as a non-standard policy tool, combines ultra-low price constraints with centralized procurement, potentially creating unique channels of influence. Although improving the institutional environment can enhance TFP by mitigating contractual risks (17, 18), administrative intervention in implementation may still lead to resource misallocation (19).

While prior studies generally acknowledge that government procurement influences firm-level TFP, the direction and magnitude of this impact remain debated due to heterogeneity in policy tools and firm characteristics. For the NCDP in particular—characterized by a combination of price regulation and demand stimulation—its micro-level transmission mechanisms warrant further empirical investigation.

> *Hypothesis 1*: The NCDP policy negatively affects the TFP of Chinese pharmaceutical manufacturers.

2.3 Heterogeneity of industrial policy's impact on TFP

Recent studies reveal substantial heterogeneity in the effects of industrial policies on firms' TFP, driven by the interplay of policy instruments, industry characteristics, and firm-level attributes. Across policy instruments, different tools—such as subsidies, tax incentives, and factor price controls—affect firms through distinct transmission channels. Zhao and Lin (20) argue that price-control-based industrial policies exhibit greater sensitivity to firm size heterogeneity, while Cao and Xia (21) find that competition-oriented industrial policies disproportionately benefit small and medium-sized enterprises (SMEs) relative to large firms.

At the industry level, labor-intensive sectors are significantly more responsive to local industrial policy initiatives than capital- or technology-intensive industries (22, 23), indicating that variations in factor intensity constitute key boundary conditions for divergent policy effects.

In terms of firm heterogeneity, state-owned enterprises (SOEs) enjoy structural advantages in accessing policy resources, stemming from their political ties (15). Moreover, differences in firm lifecycle stages and ownership structures lead to asymmetric responsiveness to policy interventions (24). Market attention further amplifies disparities in policy outcomes: analyst coverage enhances TFP through improved information discovery, with this effect varying significantly across firms (25–27).

> *Hypothesis 2*: The impact of NCDP on TFP varies depending on firms' product types, ownership structures, and levels of market attention.

2.4 The impact mechanism of industrial policy on TFP

Prior research has extensively explored the mechanisms through which industrial policies influence TFP, revealing a complex web of transmission mechanisms. From the lens of financing constraints,

industrial policies channel capital to firms through fiscal subsidies, credit support, and other instruments, which exert dual effects on TFP by easing capital constraints. On one hand, these policies act as implicit guarantees via signaling mechanisms, lowering external R&D financing costs—particularly in high R&D-intensive industries such as equipment manufacturing and pharmaceuticals—thereby boosting TFP (28, 29). On the other hand, subsidies can distort resource allocation, undermine aggregate manufacturing productivity, and erode market competition efficiency over time (30). This contradiction is especially pronounced in strategic emerging industries, where subsidies promote TFP growth for non-state-owned enterprises (31), but recurring monetary policy shocks exacerbate credit misallocation in favor of state-owned firms, ultimately diminishing investment efficiency for private enterprises (32). This underscores the moderating role of financing constraints as a core mediating variable.

R&D investment constitutes another critical channel. Industrial policies directly stimulate R&D through subsidies and tax incentives; for example, policies targeting strategic emerging industries significantly enhance innovation spending and drive TFP growth (33). Digital firms also capitalize on the signaling value of subsidies to attract external funding (34). At both firm and sectoral levels, R&D improves productivity by optimizing capital-labor allocations (35) and facilitating the reallocation of resources to more efficient industries (36). However, excessive policy intervention can incentivize excessive R&D engagement—particularly in monopolistically competitive sectors like pharmaceuticals—where firms sustain innovation through policy compensation to maintain their technological edge (16). Absent complementary regulatory measures, such interventions may crowd out productive investment, resulting in a trade-off between innovation intensity and investment efficiency (37).

The mediating role of investment efficiency predominantly follows a suppression logic. Industrial-policy-induced expansion often leads to overinvestment and excess capacity (38), while government subsidies further distort capital allocation by crowding out private investment (63). Empirical evidence supports this view, showing that key industrial policies may inhibit TFP growth by misallocating production factors (15). Notably, the interaction between financing constraints and investment efficiency amplifies policy heterogeneity: in credit-dependent sectors, non-state-owned enterprises endure a "double burden" of credit crowding-out—restricted access to financing constrains R&D capabilities and simultaneously suppresses efficient investment, leading to stagnated TFP growth (32).

In summary, industrial policies influence TFP not through a single linear pathway but via a dynamic chain of interrelated channels: financing constraints → R&D investment → investment efficiency. The positive transmission chain unfolds as follows: policy-induced capital easing → R&D acceleration → improved investment structure → TFP enhancement (39). Conversely, a negative feedback loop arises when credit misallocation suppresses market competition, encourages inefficient investment, and ultimately hinders TFP (14). These coexisting mechanisms call for policy designs that are sensitive to sector-specific attributes—such as the R&D dependence of pharmaceuticals and overcapacity risks in capital-intensive industries—and firm characteristics, especially the financial fragility of private enterprises. Dynamic optimization of policy tools, such as differentiated subsidy phase-out mechanisms, is crucial for balancing productivity gains with efficient resource allocation. The theoretical framework is illustrated in Figure 1.

> *Hypothesis 3*: The NCDP will affect firms' TFP through a chain-mediation mechanism involving financing constraints, innovation investment, and investment efficiency.

3 Data and research design

3.1 Data sources

Since the inception of the "4 + 7" NCDP pilot in 2019, the types of drugs included in NCDP contracts, the amounts of NCDP funds, and information about pharmaceutical manufacturing enterprises have been publicly disclosed during each bidding process. The procurement data for NCDP contracts come from the Shanghai Sunshine Pharmaceutical Procurement Network, where details about the winning pharmaceutical manufacturers, the unit prices of the winning products, the categories of the winning drugs, and the quantities of the winning drugs procured are disclosed. Additionally, listed pharmaceutical manufacturing companies that win bids will release announcements post-bid, detailing information such as the batch of the winning drugs, the names of the winning products, the sales volume of the winning drugs, the proportion of the winning drugs' sales volume to the total annual sales of the previous year, and whether the bid win will impact the normal production and operation of the company.

Additional data for this study are sourced from the WIND and CSMAR databases, encompassing quarterly observations of A-share listed pharmaceutical manufacturing firms in China from 2003 to 2021. The use of quarterly data is methodologically justified for several reasons. First, considering that the NCDP policy had been in effect for only three years by the end of the sample period, quarterly frequency enhances statistical power and is better suited for identifying short-term policy effects (40). Second, as shown in Table 1, NCDP bidding rounds occur multiple times annually, which makes quarterly data more precise than annual aggregates in capturing policy shocks (41). Accordingly, this study adopts quarterly data for all regression analyses. Firms designated as ST or *ST—indicating financial distress and potential delisting risk—are excluded from the sample. The final dataset consists of 310 listed firms with

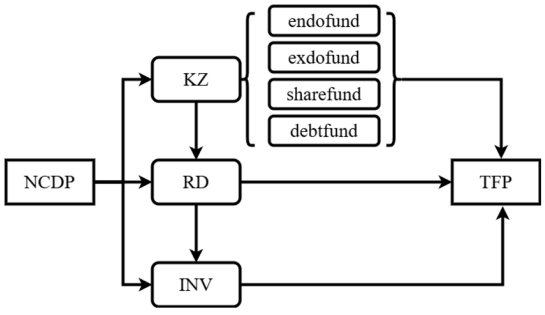


FIGURE 1
Chain-mediation effect pathway.

TABLE 1 Overview of NCDP organization.

Batch	Bid opening date	Number of procured varieties	Selection mechanism	Agreed procurement ratio	Criteria for determining winning enterprises	Institutional progress
"4 + 7" pilot	2018-12-17	25	Single winner	100%	The lowest bidding enterprise enters price negotiation.	First national-level pilot organization for drug NCDP.
Pilot expansion	2019-09-30	25	Multiple winners (≤3)	50–70%	The lowest bidding three enterprises confirm supply regions.	First national organization of a 25-province NCDP alliance.
Second batch	2020-01-21	32	Multiple winners (≤6)	50–80%	After meeting the 1.8x circuit breaker mechanism or 50% reduction protection mechanism or 0.1 yuan protection mechanism, the lowest bidding *n* enterprises confirm supply regions. *n* = maximum number of shortlisted enterprises.	Comprehensive national organization of drug NCDP; procurement documents emphasize legal responsibilities and gradually implement policies for retention of surplus medical insurance funds and a credit evaluation system.
Third batch	2020-08-24	55	Multiple winners (≤8)	40–70% for some drugs (antibiotics, hormones, etc.); others: 50–80%		
Fourth batch	2021-02-08	45	Multiple winners (≤10)			
Fifth batch	2021-06-28	61	Multiple winners (≤10)			
Sixth batch	2021-11-26	6	Multiple winners (≤8)		After meeting the 1.3x circuit breaker mechanism or 50% reduction protection mechanism, *n* = maximum number of shortlisted products.	Special procurement for insulin, with agreed procurement volume allocated based on ranking order.
Seventh batch	2022-07-13	61	Multiple winners (≤10)	50–80%	Same as Fifth Batch	Same as Fifth Batch
Eighth batch	2023-02-17	40	Multiple winners (≤10)	30–80%	Same as Fifth Batch	Same as Fifth Batch

complete and continuous reporting, ensuring data consistency and representativeness.

3.2 Dependent variable

TFP reflects the average output level per unit of input in the production process, representing the overall efficiency of converting inputs into final outputs (42). Existing studies typically measure TFP by deducting the growth rates of input factors from output growth rates (43). Common methods for estimating firm-level TFP include the Olley-Pakes (OP) method (64), the Levinsohn-Petrin (LP) method (44), and ordinary least squares (OLS).

While OLS is the most basic method for estimating TFP, it suffers from two biases: simultaneity bias and selection bias. Due to these statistical limitations, this study primarily employs the LP semi-parametric method to estimate firm-level TFP. Following Levinsohn and Petrin (44) and Lu and Lian (42), the estimation is based on firm revenue, number of employees, and capital expenditures, using cash payments for raw materials and services as a proxy for intermediate inputs in place of the investment variable proposed in the LP method. This approach allows for the estimation of firm-level TFP using the Levinsohn-Petrin productivity estimation procedure. Additionally, since the OP method effectively addresses simultaneity and selection biases, this study also uses OP-estimated TFP (TFP-OP) as an alternative dependent variable. Both LP and OP measures are used to represent firm-level TFP.

3.3 Explanatory variable

To estimate the impact of NCDP on the TFP of pharmaceutical manufacturing enterprises, the most direct method is to compare the TFP of pharmaceutical manufacturing enterprises included in the NCDP list with those not included. However, this difference may be influenced by general factors that vary over time, in addition to the impact of NCDP. Since NCDP and recognition occur in multiple periods and at different times, to exclude other interfering factors, this paper uses the multi-period difference-in-differences (DID) method to test the impact of NCDP on the TFP of pharmaceutical manufacturing enterprises. The multi-period DID method can test whether there is a significant difference in the impact on TFP between participating and non-participating enterprises before and after NCDP, controlling for other factors. As this paper uses multi-period panel data, we refer to Yue and Ye (65), and the Model (1) is set as follows:

$$TFP_{it} = \beta_0 + \beta_1 treatNCDP* + \beta_2 control_{it} + \sum Time + \sum Prov + \varepsilon_{it} \quad (1)$$

Subscripts i and t denote the firm and quarter, respectively. The key explanatory variable, $treatNCDP*$, is constructed as a multi-period difference-in-differences (DID) indicator. Following Cohen et al. (45), firm participation in the NCDP is identified through bidding contracts and publicly disclosed announcements of winning bids by listed firms. Specifically, if firm i wins an NCDP contract in quarter t, $treatNCDP*$ is set to 1 from that quarter onward and 0 for all preceding periods. For firms that never secure an NCDP contract, $treatNCDP*$ remains 0 for the entire sample period.

The vector $control_{it}$ denotes a set of control variables that vary by firm and quarter and are expected to influence TFP. $Time$ and $Prov$ represent time and province fixed effects, respectively, accounting for macroeconomic fluctuations and regional heterogeneity. Firm fixed effects are excluded to preserve degrees of freedom, avoid inflation of standard errors, and maintain the statistical power necessary to detect meaningful associations. The error term ε_{it} captures random disturbances.

3.4 Control variables

Drawing on existing literature, this study incorporates control variables from two dimensions—firm operational characteristics and corporate governance structure—to address potential confounding effects. On the operational side, we include the logarithm of firm size, tangible asset ratio, management expense ratio, and sales growth rate to control for heterogeneity in resource endowments, asset composition, operational efficiency, and market expansion capacity. Regarding corporate governance, we include the executive shareholding ratio, separation of ownership and control, proportion of independent directors, and equity balance ratio to capture the effects of managerial incentives, control rights distribution, board supervision, and shareholder oversight on firms' strategic behavior and resource allocation. Detailed definitions and measurement methods of all variables are provided in Table 2.

4 Results

4.1 Main regression results

Table 3 presents the effects of NCDP implementation on the TFP of pharmaceutical manufacturing firms. Columns (1) and (3) report regression coefficients without control variables, while controlling for time and location effects; none of these coefficients are statistically significant. Only after including enterprise-level variables and applying fixed effects for both time and location do the regression coefficients in Columns (2) and (4) become statistically significant. We suggest that the initial lack of significance is due to the error term, ε_it, incorporating unexplained variations when other factors influencing the dependent variable are not controlled, thereby inflating standard errors and obscuring statistical significance. After including the control variables, the results indicate that NCDP implementation has a statistically significant negative impact (at the 1% level) on the TFP of listed pharmaceutical firms. Based on these findings, it is clear that firms in the treatment group experienced significantly greater declines in TFP compared to the control group following the implementation of NCDP.

4.2 Robustness tests

4.2.1 Parallel trend test

For the purpose of this study, the difference-in-differences (DID) method requires that the TFP of firms in the treatment and control groups exhibit a parallel trend before the policy shock. Figure 1 depicts the estimated results of β_1 with a 95% confidence interval. It is observed that β_1 is not significant for the eight quarters preceding the policy shock, indicating that there were no substantial differences between the treatment and control groups before the implementation of the NCDP pilot policy. This observation satisfies the parallel trend assumption.

Furthermore, post-implementation, the estimated coefficient β_1 becomes significant and negative starting from the fifth quarter. This indicates that the NCDP has a negative impact on the TFP of the firms included in the NCDP list. Thus, the implementation of the NCDP has lowered the TFP of pharmaceutical manufacturing firms under its purview (see Figure 2).

4.2.2 Alternative regression method

To test the robustness of the baseline regression results, this study employs the Propensity Score Matching-Difference-in-Differences (PSM-DID) method. Considering that the effects of the NCDP pilot policy were already evident in 2018, this study conducts annual propensity score matching only for samples before the 2018 policy impact. The control variables are used as covariates for annual propensity score matching, retaining only those sample points that fall within the common support range in each matching quarter (Figure 3). A multi-period difference-in-differences test is then conducted exclusively on these samples

TABLE 2 Descriptive statistics.

Variable type	Variable symbol	Variable name	Mean	Std. Dev.	Min	Max
Dependent variables	Tfp_lp	TFP calculated using LP method	6.561	1.053	0.315	8.867
	Tfp_op	TFP calculated using ACF method	6.468	1.039	0.285	8.764
Core explanatory variable	treatNCDP	NCDP dummy variable	0.037	0.188	0.000	1.000
Firm-level control variables	Size	Firm size	21.707	1.013	17.813	24.271
	ESR	Executive shareholding ratio	11.164	17.989	0.000	64.523
	TA	Tangible assets	3.230	2.660	0.000	14.414
	MER	Management expense ratio	0.102	0.053	0.005	0.289
	STR	Separation of two rights	5.986	7.958	−21.590	29.829
	PID	Proportion of independent directors	36.641	5.047	0.000	50.000
	EBD	Equity balance degree	0.726	0.582	0.006	2.600
	SGR	Sales growth rate	0.341	0.695	−1.000	1.897

TABLE 3 Results of main sample regression.

	(1)	(2)	(3)	(4)
	tfp_lp	tfp_lp	tfp_op	tfp_op
treatNCDP	0.004 (0.053)	−0.183*** (0.039)	−0.046 (0.050)	−0.198*** (0.039)
Size		0.515*** (0.010)		0.460*** (0.010)
ESR		0.006*** (0.000)		0.006*** (0.000)
TA		0.143*** (0.004)		0.141*** (0.004)
MER		−3.966*** (0.190)		−3.898*** (0.189)
STR		0.003*** (0.001)		0.003*** (0.001)
PID		−0.010*** (0.002)		−0.010*** (0.002)
EBD		0.030** (0.014)		0.044*** (0.015)
SGR		0.147*** (0.045)		0.154*** (0.045)
_cons	6.561*** (0.009)	−4.448*** (0.231)	6.469*** (0.009)	−3.374*** (0.231)
Time fixed effects	Control	Control	Control	Control
Province fixed effects	Control	Control	Control	Control
Observations	9,634	9,634	9,634	9,634
R-squared	0.310	0.563	0.322	0.549

Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

within the common support range. As shown in the first column of Table 4, the coefficients of the multi-period DID variable are significantly negative at the 1% level. Therefore, the baseline regression results of this study are robust.

4.2.3 Excluding the impact of financial markets on TFP

To avoid the interference of the financial crisis and government assistance policies for enterprises on the regression results, this study excludes samples from before 2011. The TFP calculated by the LP method is then re-regressed. As shown in the second column of Table 4, the regression coefficient of treatNCDP remains significantly negative, indicating that the research findings of this study are reliable.

4.2.4 Extending the forecast window

To test the robustness of the core effects over a longer time horizon, we extended the original regression timeline and expanded the prediction window. In columns (3) and (4) of Table 4, the core dependent variables were lagged by one period and two periods, respectively. The results show that statistically significant outcomes persist even with an extended observational window, indicating that the negative impact of NCDP on enterprise TFP has long-term sustainability. This temporal misalignment approach helps mitigate causal identification issues to some extent, thereby reinforcing the robustness of the findings over extended timeframes.

4.2.5 Substitution of dependent variables

To test robustness, we replaced the measurement methodology by calculating TFP using the Olley-Pakes (OP) and ordinary least squares (OLS) methods, as alternatives to the Levinsohn-Petrin (LP) approach. Columns (3) and (4) in Table 2, and column (5) in Table 4, present the regression results after substituting LP with OP and OLS methodologies. The outcomes are consistent with the baseline regression findings, confirming the robustness of the primary results across alternative TFP measurement frameworks.

4.2.6 Placebo test

To verify that the observed changes in pharmaceutical manufacturers' TFP are driven by the NCDP and not by unobserved confounding factors, we conducted a placebo test using randomized treatment group assignment. By performing 500 iterations of random sampling and regression, we generated kernel density estimates for the coefficient distribution of the key independent variable (Figure 4). The placebo test results show that the coefficients cluster around zero, with the majority being statistically insignificant. Only a small fraction of coefficients deviate below the true regression coefficient, providing strong evidence that the TFP changes in pharmaceutical enterprises are primarily attributable to the NCDP rather than random noise or external shocks.

4.3 Heterogeneity analysis

Previous empirical results show that the demand-side industrial policy, the NCDP, has reduced the TFP of pharmaceutical manufacturing enterprises. Demand-side industrial policies involve government interventions that replace market mechanisms to regulate corporate behavior. In this context, the impact of selective industrial policies may vary across firms with different characteristics. Therefore, if the decline in corporate TFP is attributable to NCDP implementation, this effect should vary across firms with different characteristics. Building on this, the study investigates the mechanisms through which NCDP affects TFP by examining cross-sectional differences in the impact of industrial policy shocks. It uses grouped regression methods, focusing on factors such as firm ownership, product characteristics, and analyst attention.

4.3.1 Ownership-based examination

How does firm ownership influence TFP changes during NCDP implementation? To analyze the relationship between industrial policy and firm heterogeneity, Model (2) is specified. The grouping criterion differentiates state-owned enterprises (SOEs, coded SOE = 1) from non-state-owned enterprises (non-SOEs, coded SOE = 0).

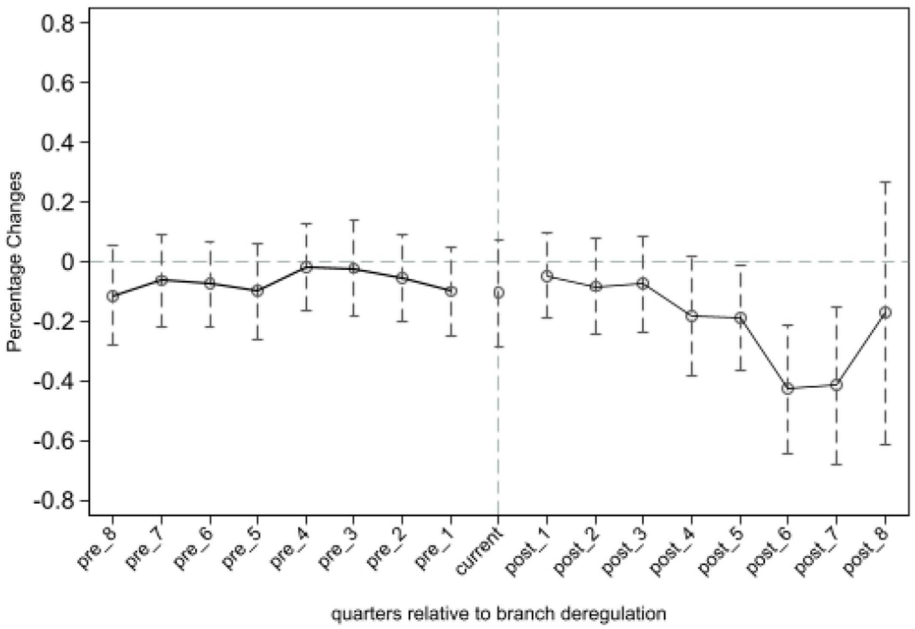


FIGURE 2
Parallel trend test.

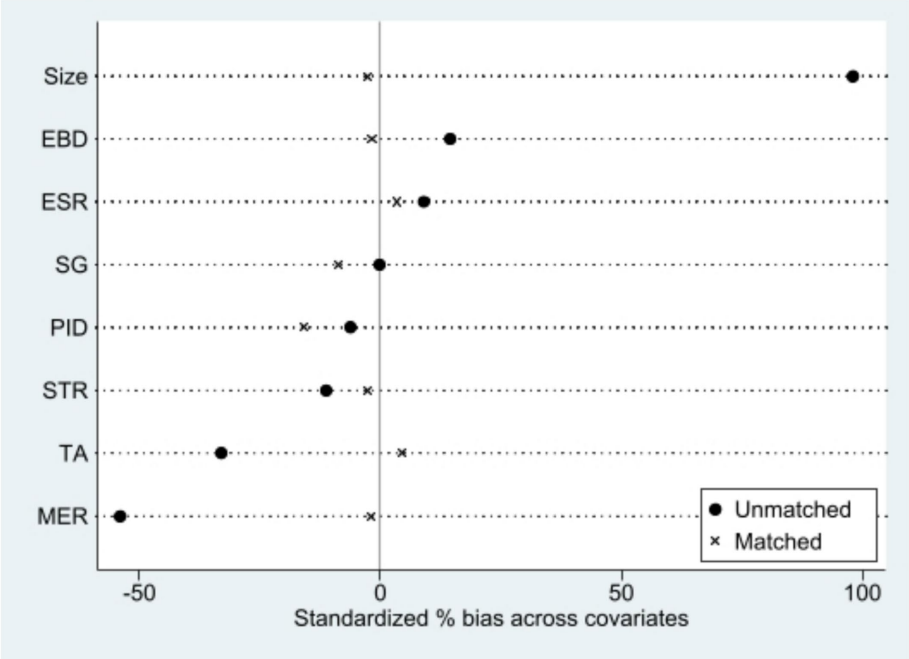


FIGURE 3
Propensity score distribution after matching.

$$TFP_{it} = \beta_0 + \beta_1 treatNCDP* + \beta_2 SOE_{it} + \beta_3 control_{it} + \sum Time + \sum Prov + \varepsilon_{it} \quad (2)$$

The grouping test results based on firm ownership are shown in columns (1) and (2) of Table 5. The regression results show a negative coefficient for non-state-owned enterprises (non-SOEs), indicating that the NCDP shock significantly reduced their TFP. The results further indicate that non-SOEs are more sensitive to industrial policy shocks than state-owned enterprises (SOEs). These findings suggest that the TFP-reducing effect of NCDP is more pronounced for non-SOEs than for SOEs.

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TABLE 4 Robustness tests.

	(1) PSM-DID	(2) Time Change DID	(3) L.tfp_lp	(4) L2.tfp_lp	(5) tfp_ols
treatNCDP	−0.607*** (0.155)	−0.169*** (0.038)	−0.188*** (0.037)	−0.161*** (0.039)	−0.141*** (0.036)
_cons	−2.275 (1.378)	−4.144*** (0.285)	−4.385*** (0.228)	−4.656*** (0.245)	−1.569*** (0.219)
Controls	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Controls	Controls	Controls	Controls	Controls
Province fixed effects	Controls	Controls	Controls	Controls	Controls
Observations	8,637	5,937	9,048	8,637	9,634
R2	0.764	0.555	0.571	0.554	0.638

Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

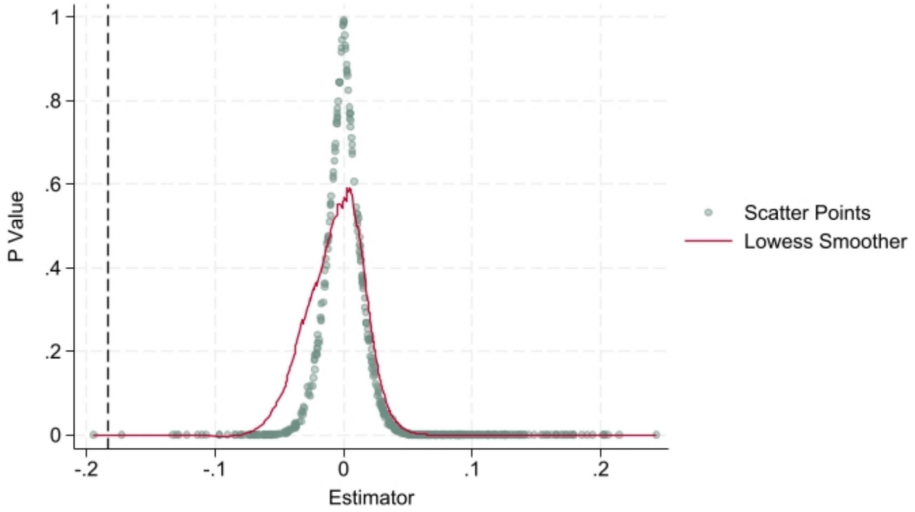


FIGURE 4
Placebo test results.

In practice, state-owned pharmaceutical manufacturers are primary suppliers of essential drugs to Chinese medical institutions, with government-appointed management and government-controlled entities at various levels. Their products inherently serve quasi-public welfare purposes rather than being purely profit-driven, with low profit margins and high production volumes. The NCDP's primary aim—reducing drug prices through centralized procurement while ensuring supply volumes—aligns with the founding purpose of SOEs. As SOEs primarily produce high-volume, low-price drugs with stable demand, the policy has limited disruptive effects on their operations. Therefore, the policy's impact on SOEs remains statistically insignificant.

From another perspective, governments, as bulk purchasers, have strong bargaining power to suppress prices and control accounts receivable, generally weakening supplier performance. However, this pressure diminishes when suppliers improve their own bargaining power. Compared to private firms, SOEs benefit from political affiliations, policy support, resource advantages, and strong financial capacities, which give them better negotiation power. This explains why the negative impact of customer concentration on performance is primarily observed in private enterprises. In the pharmaceutical industry, listed non-SOEs typically maintain higher profit margins. Participation in NCDP subjects their profitability to substantial shocks. As a result, non-SOEs experience greater declines in TFP than SOEs under this policy regime.

4.3.2 Product heterogeneity-based examination

As a distinct category of pharmaceutical manufacturers in China, Traditional Chinese Medicine (TCM) producers hold a significant share in the national drug supply system. To empirically investigate whether differences in TFP exist between TCM and non-TCM manufacturers under the NCDP policy, this study uses the following Model (3). The grouping criterion distinguishes TCM manufacturers (coded as TCM = 1) from Western medicine manufacturers (coded as TCM = 0).

$$TFP_{it} = \beta_0 + \beta_1 treatNCDP* + \beta_2 TCM_{it} + \beta_3 control_{it} + \sum Time + \sum Prov + å_{it} \quad (3)$$

The results are presented in columns (3) and (4) of Table 5. The regression results indicate that the coefficient for Western medicine manufacturers is negative and statistically significant, while the coefficient for TCM manufacturers is not significant. This confirms that the NCDP shock significantly reduces the TFP of Western

TABLE 5 Heterogeneity analysis.

	Ownership heterogeneity		Product heterogeneity		Analyst coverage heterogeneity	
	(1) soe = 1	(2) soe = 0	(3) TCM = 1	(4) TCM = 0	(5) AnCov = 1	(6) AnCov = 0
	tfp_lp	tfp_lp	tfp_lp	tfp_lp	tfp_lp	tfp_lp
treatNCDP	−0.092 (0.071)	−0.268*** (0.045)	0.049 (0.064)	−0.246*** (0.043)	−0.348*** (0.060)	0.020 (0.044)
_cons	−3.729*** (0.523)	−4.612*** (0.318)	−8.979*** (0.446)	−2.879*** (0.309)	−3.775*** (0.550)	−3.216*** (0.274)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Controls	Controls	Controls	Controls	Controls	Controls
Province fixed effects	Controls	Controls	Controls	Controls	Controls	Controls
Observations	2,777	5,859	3,010	5,627	2,560	6,077
R-squared	0.649	0.516	0.654	0.521	0.504	0.585

Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

medicine manufacturers but does not have a significant impact on TCM manufacturers.

Several factors contribute to this result. Firstly, TCM products lack a standardized national quality system, making it difficult to differentiate quality levels. The regulatory authorities have not yet established a comprehensive quality system for TCM formulations, limiting the basis for implementing a "quality-based pricing" management approach. Secondly, the production and pricing of TCM formulations are influenced by various factors. TCM formulations are derived from herbal medicines, which are agricultural products affected by factors such as region, climate, and environment. As a result, production supply is unstable and prices fluctuate frequently. Therefore, the prices of TCM products are traditionally regulated by market mechanisms and vary with market conditions. Lastly, the use of TCM formulations varies significantly among medical institutions. Different regions, hospitals, and medical practices use different TCM products, making it challenging to implement a nationwide NCDP model. Instead, smaller-scale procurement at the county level or within regional medical communities may be more appropriate. Given that TCM formulations were not included as primary targets in the NCDP, the policy does not significantly impact the TFP of TCM manufacturing enterprises.

4.3.3 Analyst coverage-based examination

Securities analysts serve as important information intermediaries in capital markets. They can access information promptly, utilize their knowledge and analytical skills, generate and disseminate firm-specific information, reduce information asymmetry between internal (management) and external (investors) stakeholders, and improve capital allocation efficiency (46). When analysts anticipate a decline in firm performance, they may downgrade their ratings, prompting investors to react negatively, adversely affecting the firm's stock price (47). Within the operational implementation of the NCDP policy, the inclusion of enterprises inevitably exerts profit-level impacts that disrupt business operations. To investigate whether differential market attention affects corporate TFP, this study employs Model (4), where pharmaceutical manufacturers under analyst coverage are coded as $AnCov = 1$ and those without analyst coverage as $AnCov = 0$:

$$TFP_{it} = \beta_0 + \beta_1 treatNCDP * + \beta_2 AnCov_{it} + \beta_3 control_{it} + \sum Time + \sum Prov + \varepsilon_{it} \quad (4)$$

Based on the heterogeneity of analyst attention, the results of the grouped test are presented in Columns 5 and 6 of Table 5. In the context of NCDP implementation, the policy inevitably affects the profitability of the included firms. The empirical results from the heterogeneity analysis indicate that TFP is indeed influenced by analyst coverage. Some literature suggests that when firms fail to meet analysts' earnings forecasts, they may reduce future R&D investments, negatively impacting innovation (48). Therefore, under analyst coverage, NCDP negatively impacts enterprise TFP.

4.4 Mechanisms of influence test

4.4.1 Financing constraints and TFP

The preceding analysis has established the relationship between the NCDP policy and the TFP of pharmaceutical manufacturers. The next step is to examine the mediating pathways through which NCDP influences TFP. Since NCDP impacts corporate operating performance, the resulting changes in financing constraints may disrupt investment activities such as in fixed assets and R&D, thus affecting productivity levels (49, 50). This study proposes the transmission pathway: NCDP → Financing Constraints → TFP, and empirically measures the role of financing constraints in this process.

To test the hypothesis regarding NCDP's impact on financing constraints, this study employs the Kaplan-Zingales (KZ) index as a proxy. Following Wei et al. (18), we construct the KZ index using data from Chinese listed pharmaceutical companies to estimate the level of financing constraints (KZ) for each firm. A higher KZ value indicates greater financing constraints. Additionally, we investigate how financing constraints influence TFP through changes in specific financing channels. To this end, we establish a financing structure framework, substituting the mediating variable KZ with endogenous financing (endofund), exogenous financing (exdofund), and two exogenous financing channels: equity financing (sharefund) and debt financing (debtfund).

In defining variables, this study follows the approach of Lu et al. (51) to measure endogenous financing, using cash flow derived from adjusted net profit. This is deemed more appropriate as retained earnings, which represent internally generated funds, face fewer usage restrictions. Exogenous financing is measured by the net cash flow from financing activities as reported in the corporate cash flow statements. For current-period debt financing, we use the change in the sum of long-term loans and bonds payable under long-term

liabilities in the balance sheet. Equity financing is measured as the change in the sum of common stock and capital surplus. To control for firm size effects, all four variables—endogenous financing, exogenous financing, debt financing, and equity financing—are scaled by the total assets of the listed companies for the corresponding period.

We construct the following mediating effect models: Mediating Effect Models (5, 6) for NCDP's Impact on TFP via Financing Constraints:

$$KZ_{it} = \gamma_0 + \gamma_1 treatNCDP** + \gamma_2 control_{it} + \sum Time + \sum Prov + \varepsilon_{it} \quad (5)$$

$$TFP_{it} = \beta_0 + \beta_1 treatNCDP** + \beta_2 KZ_{it} + \beta_3 control_{it} + \sum Time + \sum Prov + \varepsilon_{it} \quad (6)$$

Mediating Effect Models (7, 8) for NCDP's structural impact on TFP via financing constraints:

$$\begin{matrix}\text{endofund}_{it} / \text{exdofund}_{it} / \\ \text{sharefund}_{it} / \ \text{debtfund}_{it}\end{matrix} = \gamma_0 + \gamma_1 treatNCDP** + \gamma_2 control_{it} + \sum Time + \sum Prov + \varepsilon_{it} \quad (7)$$

$$TFP_{it} = \beta_0 + \beta_1 treatNCDP** + \beta_2 \begin{pmatrix}\text{endofund}_{it} / \text{exdofund}_{it} / \\ \text{sharefund}_{it} / \ \text{debtfund}_{it}\end{pmatrix} + \beta_3 control_{it} + \sum Time + \sum Prov + \varepsilon_{it} \quad (8)$$

Table 6 (columns 1–6) presents the empirical results of the mediating effect tests. The findings indicate that the NCDP policy reduces pharmaceutical manufacturers' TFP by exacerbating their financing constraints. This result aligns with existing literature, which widely supports the idea that heightened financing constraints lead to declines in TFP (52–54), confirming conventional understanding.

The coefficients for the impacts of endogenous financing (endofund), exogenous financing (exdofund), and equity financing (sharefund) in the financing structure are significantly negative: −0.008, −0.013, and −0.013, with significance levels of 1, 5, and 1%, respectively. These results suggest that the NCDP policy disrupts pharmaceutical manufacturers' financing channels by reducing internal, external, and equity financing, thereby intensifying financing constraints. In contrast, the mediating effect of debt financing (debtfund) is statistically insignificant, implying that the NCDP does not reduce TFP through debt financing.

These findings can be interpreted as follows: When the NCDP exacerbates financing constraints, external funding becomes less accessible, and financing costs rise significantly. Firms are forced to rely on internal funds for fixed investments. However, due to reduced retained earnings and the large scale of required investments, internal funds alone are insufficient to meet investment needs. As a result, firms often forgo profitable investment opportunities, leading to resource misallocation and productivity losses (55). In conclusion, the NCDP policy ultimately reduces TFP by amplifying financing constraints for pharmaceutical manufacturers.

4.4.2 R&D investment, inefficient investment, and TFP

Building on the theoretical analysis above, which suggests that industrial policies may influence corporate TFP through two primary channels—R&D investment and investment efficiency—this study constructs the following mediating effect framework to validate this transmission mechanism. First, we clarify the measurement methods for the core mediating variables. R&D investment (RD) is measured as the ratio of quarterly R&D expenditure to operating revenue for China's A-share listed pharmaceutical firms. This metric, consistent with the definition of R&D expenditure in the Accounting Standards for Business Enterprises, effectively reflects firms' sustained resource allocation to technological innovation activities (56). Inefficient investment (invest) is estimated using the residual method from Richardson's (57) expected investment Model (9).

$$invest_{it} = \alpha_0 + \alpha_1 Size_{it-1} + \alpha_2 Lev_{it-1} + \alpha_3 Growth_{it-1} + \alpha_4 Roa_{it-1} + \alpha_5 Age_{it-1} + \alpha_6 Cash_{it-1} + \alpha_7 \text{invest}_{it-1} + \sum Time + \sum Ind + \varepsilon_{it-1} \quad (9)$$

Specifically, the dependent variable is defined as the ratio of net capital expenditures (net cash flow from the acquisition and disposal of long-term assets) to total assets at the beginning of the period. The independent variables include: $Size_{it-1}$, which represents the natural logarithm of total assets for firm i in period t − 1; Lev_{it-1}, denoting the leverage ratio, calculated as total liabilities divided by total assets; $Growth_{it-1}$, reflecting the total asset growth rate; Roa_{it-1}, measuring return on assets, defined as net profit relative to total assets; Age_{it-1}, indicating firm age; and $Cash_{it-1}$, capturing cash flow intensity, expressed as operating cash flow scaled by total assets. The residual term is denoted as ε_{it}, with year and industry fixed effects controlled for. The absolute

TABLE 6 Impact mechanisms of financing constraints on TFP.

	(1)	(2)	(3)	(4)	(5)	(6)
	KZ	tfp_lp	endofund	exdofund	sharefund	debtfund
treatNCDP	0.736*** (0.094)	−0.050*** (0.013)	−0.008*** (0.003)	−0.013** (0.005)	−0.013*** (0.004)	−0.000 (0.003)
KZ		−0.141*** (0.008)				
_cons	−2.729*** (0.637)	−4.955*** (0.248)	−0.087*** (0.019)	0.033 (0.031)	0.064** (0.027)	−0.031 (0.021)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Controls	Controls	Controls	Controls	Controls	Controls
Province fixed effects	Controls	Controls	Controls	Controls	Controls	Controls
Observations	9,634	9,634	9,634	9,634	9,634	9,634
R-squared	0.197	0.610	0.257	0.077	0.097	0.064

Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

value of the regression residuals represents the degree of inefficient investment (INV), where positive residuals indicate over-investment and negative residuals reflect under-investment. This study takes the absolute value of the residuals for both over- and under-investment to construct INV, which captures the overall level of inefficient investment.

Building on this foundation, this study constructs a three-stage recursive model system to systematically examine the transmission mechanism. First, Model (10) investigates the impact of industrial policy (treatNCDP∗) on mediating variables (RD/INV). Model (11) tests the effect of mediating variables on TFP. Furthermore, to address potential chained mediating effects, Model (12) is introduced to analyze the transmission role of R&D investment on inefficient investment. The specific model specifications are as follows:

$$RD_{it}\ /\ INV_{it} = \gamma_0 + \gamma_1 treatNCDP* + \gamma_2 control_{it} + \sum Time + \sum Prov + \varepsilon_{it} \quad (10)$$

$$TFP_{it} = \beta_0 + \beta_1 treatNCDP* + \beta_2\left(RD_{it} - INV_{it}\right) + \beta_3 control_{it} + \sum Time + \sum Prov + \varepsilon_{it} \quad (11)$$

$$INV_{it} = \gamma_0 + \gamma_1 treatNCDP* + \gamma_2 RD_{it} + \gamma_3 control_{it} + \sum Time + \sum Prov + \varepsilon_{it} \quad (12)$$

Through Models (10, 11), the independent mediating effects of R&D investment and investment efficiency can be identified. The inclusion of Model (12) further uncovers the "R&D investment → investment efficiency optimization → productivity enhancement" chain-mediated pathway, thereby systematically dissecting the multi-tiered mechanisms through which industrial policies influence corporate TFP.

According to the regression results in Table 7, the direct effect coefficient of NCDP on R&D investment is 0.009 and significantly positive, indicating that the policy effectively incentivizes corporate R&D activities. However, the results reveal that the direct effect coefficient of R&D investment on TFP is −0.133 and significantly negative, which contradicts the widely accepted view in the literature that "R&D investment enhances TFP growth." To explain this paradox, a novel perspective is required: the productivity-enhancing effect of R&D investment exhibits a significant time lag, as technological transformation and market validation are needed to realize R&D outcomes (55, 58). In the short term, efficiency losses may arise due to resource crowding-out (32). This mechanism is further validated in our study—columns (3)–(5) of Table 6 demonstrate that the NCDP policy significantly increases corporate inefficient investment (INV), and this mediating effect through inefficient investment leads to a decline in TFP. Drawing on the theoretical framework of Czarnitzki and Hottenrott (59), the expansion of R&D investment under NCDP conditions may crowd out liquidity and productive capital for equipment renewal, resulting in a "R&D expansion-production contraction" resource allocation imbalance that exacerbates investment inefficiency. The empirical results also support this logic. Consequently, three mutually reinforcing mediating pathways are identified:

NCDP → RD↑ → TFP↓;
NCDP → INV↑ → TFP↓;
NCDP → RD↑ → INV↑ → TFP↓

4.4.3 Financing constraints, R&D investment, and inefficient investment

Building on existing theoretical frameworks and supporting literature, this study posits that NCDP may influence TFP by exacerbating corporate financing constraints (KZ). These constraints, in turn, affect TFP through two distinct pathways: R&D investment (RD) and inefficient investment (INV). To validate this mechanism, the study constructs sequential regression models:

First, Model (13) is employed to examine the impact of NCDP on KZ:

$$KZ_{it} = \gamma_0 + \gamma_1 treatNCDP* + \gamma_2 control_{it} + \sum Time + \sum Prov + \varepsilon_{it} \quad (13)$$

Subsequently, Model (14) is utilized to test the effects of financing constraints on the mediating variables RD and INV:

$$RD_{it}\ /\ INV_{it} = \beta_0 + \beta_1 treatNCDP* + \beta_2 KZ_{it} + \beta_3 control_{it} + \sum Time + \sum Prov + \varepsilon_{it} \quad (14)$$

The regression results in Table 8 reveal that, after controlling for time and province fixed effects, financing constraints (KZ) have a significantly positive direct effect on R&D investment (RD), with a coefficient of 0.011, and also exhibit a significantly positive coefficient of 0.007 on inefficient investment (INV). This seemingly paradoxical finding can be explained theoretically: on one hand, when firms face financing constraints, they may adopt a "flight-to-quality" strategy (60), increasing R&D investments to build technological barriers in exchange for capital market recognition or policy preferences. On the other hand, credit resource crowding-out forces firms to reduce strategic investments and pursue short-term high-risk projects, leading to deteriorating investment efficiency (61). The coexistence of these two pathways suggests that financing constraints exert a dual effect on corporate behavior, driving both "innovation incentives" and "investment distortions." The underlying drivers of these effects can be traced to policy-driven expectations of R&D subsidies (59) and resource substitution behaviors induced by credit rationing (62). Consequently, this study identifies two competing transmission channels, with the net effect of industrial policies on productivity determined by the interplay of these opposing mechanisms.

NCDP → KZ↑ → RD↑ → TFP↑,
NCDP → KZ↑ → INV↑ → TFP↓

5 Conclusion

5.1 Research findings

This study empirically examines the impact of the National Drug Price Control Policy (NCDP) on TFP of pharmaceutical firms using quarterly data from A-share listed pharmaceutical manufacturing companies in China from 2003 to 2021. The results show that NCDP significantly hinders the improvement of corporate TFP, with the negative impact being most pronounced in non-state-owned enterprises, non-traditional Chinese medicine producers, and firms with high analyst coverage. Mechanistically, NCDP directly suppresses TFP by exacerbating financing constraints (KZ↑), which manifest as reductions in internal, external, and equity financing

TABLE 7 Impact mechanisms of R&D investment and inefficient investment on TFP.

	(1)	(2)	(3)	(4)	(5)
	RD	tfp_lp	INV	tfp_lp	INV
treatNCDP	0.009*** (0.003)	−0.133*** (0.039)	0.006** (0.003)	−0.144*** (0.051)	0.009*** (0.003)
RD		−2.183*** (0.314)			0.123*** (0.032)
INV				−1.215*** (0.281)	
_cons	0.006 (0.009)	−4.638*** (0.245)	0.006 (0.020)	−3.899*** (0.287)	0.019 (0.018)
Observations	8,637	8,637	4,865	4,803	5,408
Controls	Yes	Yes	Yes	Yes	Yes
Time Fixed Effects	Controls	Controls	Controls	Controls	Controls
Province Fixed Effects	Controls	Controls	Controls	Controls	Controls
R-squared	0.528	0.557	0.179	0.583	0.183

Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

TABLE 8 Impact mechanisms of financing constraints on R&D investment and investment inefficiency.

	(1)	(2)	(3)
	KZ	RD	INV
treatNCDP	0.736*** (0.094)	0.011*** (0.003)	0.007*** (0.003)
KZ		−0.003*** (0.000)	0.002*** (0.000)
_cons	−2.729*** (0.637)	0.007 (0.009)	0.027 (0.019)
Controls	Yes	Yes	Yes
Time fixed effects	Controls	Controls	Controls
Province fixed effects	Controls	Controls	Controls
Observations	9,634	8,446	4,744
R-squared	0.197	0.541	0.186

Robust standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

capabilities, thus diminishing capital allocation efficiency. In addition, financing constraints indirectly affect TFP through two channels: on one hand, they push firms to increase R&D investments (RD↑), but the time lag in innovation conversion prevents these efforts from translating into immediate productivity gains; on the other hand, they lead to inefficient investments (INV↑), causing capital misallocation and efficiency losses. While R&D expenditures rise in the short term, they result in a "resource crowding-out and substitutive squeezing effect," which, in turn, worsens investment efficiency and amplifies the negative impact on TFP through the "NCDP→RD↑ → INV↑ → TFP↓" transmission chain. These findings suggest that, while NCDP offers public welfare benefits by reducing drug costs, its negative effects on corporate financing capacity, investment efficiency, and forced R&D escalation may undermine the long-term development of firms, creating a trade-off between "policy dividends and enterprise efficiency."

5.2 Policy implications

To balance the public welfare objectives of NCDP with the long-term sustainability of pharmaceutical companies, the following policy recommendations are made based on the empirical findings:

First, establish a categorized support system and multi-tiered financing safeguards. Policy design should be tailored to address the diverse impacts of NCDP across firms. For non-state-owned enterprises, non-traditional Chinese medicine producers, and firms with high analyst visibility that are disproportionately affected by the policy, differentiated compensation mechanisms should be incorporated into price control policies. These could include relaxing loan access restrictions, streamlining equity issuance approvals to reduce external financing constraints, and enhancing internal financing capacity through tax rebates and retained earnings subsidies. Additionally, strengthen policy-driven financial tools by introducing industry-specific credit quotas for pharmaceuticals, exploring supply chain finance and intellectual property pledge financing models, and guiding private capital into innovative drug R&D to address the "financing difficulty → low investment efficiency → R&D resource crowding-out" dilemma.

Second, align innovation incentives with endogenous corporate reforms. In terms of R&D support, policy should include proportional VAT and income tax deductions for corporate R&D expenditures, phased subsidies for clinical trials of innovative drugs, and the establishment of patent commercialization reward funds to mitigate resource displacement risks. Furthermore, equity incentive schemes for core R&D personnel should link compensation to innovation outcomes, boosting human capital returns. In corporate governance, firms should optimize capacity structures by divesting low-efficiency assets and focusing on high-margin product lines to enhance capital

allocation efficiency. Investment decision-making processes should be refined through dynamic project evaluation and risk-warning systems to mitigate TFP erosion caused by inefficient investments. Finally, the creation of a dynamic NCDP policy monitoring platform should be considered to periodically assess the relationship between price controls and productivity fluctuations. This platform would help achieve long-term equilibrium between "price containment and efficiency enhancement" through flexible pricing mechanisms and phased compensation policies.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: https://data.csmar.com/.

Author contributions

XL: Funding acquisition, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. RT: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. WZ: Conceptualization, Formal analysis, Methodology, Project administration, Software, Visualization, Writing – review & editing. YJ: Formal analysis, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Can the accepting foreign clinical data policy improve innovation investment of pharmaceutical firms? Empirical evidence from China

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Introduction: In October 2017, China initiated adjustments to the registration procedures for imported drugs to promote accessibility to overseas drugs. In support of this decision, the National Medical Products Administration (NMPA) issued a technical guideline regarding accepting foreign clinical trial data in July 2018. Collectively referred to as the accepting foreign clinical data policy, these measures have accelerated the influx of overseas drugs into China.

Methods: Using the panel data from 104 A-share pharmaceutical listed firms between 2013 and 2024, this study conducted a difference-in-differences model to explore the impact of this policy on the innovation investment of Chinese pharmaceutical firms and further analyzed the underlying moderating effect.

Results: The results demonstrate a significantly positive effect of this accepting foreign clinical data policy on pharmaceutical firms' innovation investment, which is verified with the parallel trend and robustness tests. Further analysis indicates that corporate absorptive capacity positively moderates the relationship between the policy implementation and innovation investment. In addition, the heterogeneity analysis suggests that this policy has a more significant effect on firms that are non-state-owned, engage in new drug research and have strong market power.

Discussion: This study serves as a significant supplement to the current literature regarding the accepting foreign clinical data policy and innovation investment, providing valuable insights for policymakers and R&D decision-makers in the pharmaceutical sector.

KEYWORDS

foreign clinical data, innovation investment, difference-in-differences model, pharmaceutical firms, absorptive capacity

1 Introduction

Clinical trials are the most time-consuming and expensive steps during the research and development (R&D) process of new drugs, which provide substantial evidence to evaluate the efficacy and safety of drugs for the registration and approval of drugs (1). With the accelerating globalization of pharmaceutical clinical research and development, more and more pharmaceutical firms are conducting international multi-regional clinical trials (MRCTs) to support global registration applications, so as to improve R&D efficiency, reduce costs and unnecessary redundant studies, and expand market shares (2). However, the simultaneous conduct of clinical

trials for new drugs worldwide and the acceptance of foreign clinical data is often hampered by differences in drug registration and clinical trial administration systems between countries or regions. Moreover, different national regulatory authorities have different understandings of foreign clinical data due to differences in technical review requirements, ethnic populations of the subjects, clinical trial conditions and other factors affecting clinical trial outcomes. These differences make it complicated and controversial for them to accept foreign clinical trial data for marketing applications of overseas drugs (3).

In the United States, according to Title 21 of the Code of Federal Regulations, Part 314.106, regulations since 1985 have explicitly contemplated reliance on non-US data as part of, or even as the entire basis for drug approval, provided that the foreign data are applicable to the US population and medical practice (2). In Europe, it was reported as early as 1988 that the quality of clinical data, regardless of its origin, was the determining factor for marketing authorization in the European Community and other countries (4). In Japan, the earliest country in Asia to introduce the International Conference on Harmonization E5 (ICH-E5) in 1998, simultaneous conduct of clinical trials for foreign new drugs was permitted. However, due to the differences in cultural and ethnic factors, as well as relatively strict and conservative supervision, additional local clinical trials were necessary to meet Japanese regulatory requirements (3). With the globalization of clinical research and the accumulation of ethnic data, regulatory authorities are progressively adopting new scientific evaluation methodologies and exhibiting a more open stance toward accepting foreign clinical data.

In China, the regulatory authority applied stringent requirements for initiation of clinical trials and acceptance of foreign clinical data in the past (5). Clinical trials were not allowed to be simultaneously conducted in China and abroad, and supplementary clinical development programs specifically involving Chinese patients were compulsory (6). It was not until October 2017 that the Chinese regulatory authority abolished the requirements that a new drug must have initiated at least a phase 2 trial overseas before Chinese sites participate in the MRCT and must obtain marketing authorization from other countries before applying for approval in China (6–8). In addition, marketing applications can be submitted directly for overseas drugs with MRCTs containing Chinese data. Subsequently, in order to further encourage the simultaneous R&D process and expedite the marketing process of overseas new drugs in China, the regulatory authority issued the guidance on accepting foreign clinical trial data and established a special approval channel for urgently needed overseas new drugs in 2018 (9, 10). Collectively referred to as "accepting foreign clinical data" in this paper, these measures encourage a shift in the R&D strategy of imported drugs toward participation in MRCTs in China prior to approval, resulting in an increase in the number of MRCTs conducted in China (7, 11). In addition, the approval time for imported drugs has been significantly shortened (12). As a result, the policy of accepting foreign clinical data has encouraged the registration applications of overseas drugs and accelerated their entry in China. As shown in Figure 1, the number of clinical trial and marketing applications for imported drugs has increased by two to three times since 2018. Consequently, the accepting foreign clinical data policy has undoubtedly enhanced the import competition in Chinese pharmaceutical industry.

Continuous innovation consistently serves as the pivotal source of competitive advantage in the pharmaceutical sector (13). To enhance the innovation capabilities of pharmaceutical firms and meet the evolving clinical needs of residents, the Chinese government has implemented a series of reforms and policies in this field, including consistency evaluations of generic drugs (14, 15), volume-based procurement (16), price negotiation in medical insurance (17), and the Marketing Authorization Holder system (13). Empirical evidence has verified that these policies effectively stimulate corporate innovation. The policy of accepting foreign clinical data, which is a key reform in the drug registration system, facilitates the influx of overseas drugs and subsequently increases the import competition. As there is still a significant gap between Chinese firms and international experienced firms in terms of innovation capabilities, funds, talents and management systems (17), this policy will have a great impact on

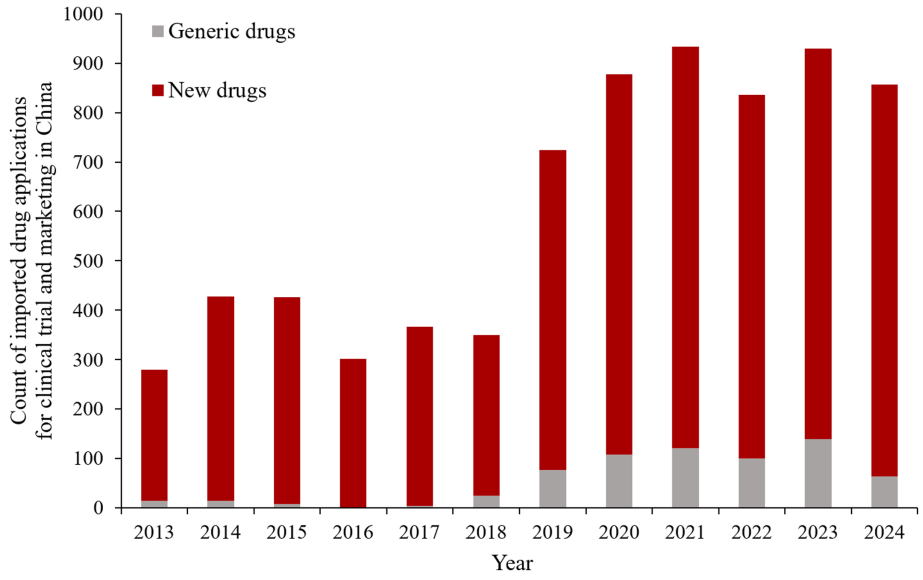


FIGURE 1
The count of imported drug applications for clinical trial and marketing in China. *Data from Yao Zhi, https://db.yaozh.com/.

the innovation incentives of Chinese pharmaceutical firms due to intensified import shock. Some industry scholars argue that this policy will put tremendous pressure on domestic firms and discourage their further innovative efforts, while others believe that it will force domestic firms to invest more in innovation to improve their competitiveness (18). To date, studies on the relationship between the accepting foreign clinical data policy and pharmaceutical firms' innovation is lacking and no consensus has been reached.

To address the aforementioned questions, we conduct a theoretical analysis of how the accepting foreign clinical data policy influences innovation investment of Chinese pharmaceutical firms based on the marketing competition effect and technological spillover effect. Subsequently, this paper considers this policy as a quasi-natural experiment and takes 104 A-share listed pharmaceutical firms from 2013 to 2024 as the research samples for empirical verification by a difference-in-differences (DID) model. Furthermore, given that absorptive capacity can influence corporate innovation in extant research (19), we also examine the moderating role of corporate absorptive capacity in the relationship between this policy and innovation investment. In summary, the objective of this study is to validate whether the implementation of the accepting clinical foreign policy in China can effectively stimulate the innovation incentives among pharmaceutical firms and to explore its underlying influencing mechanism. This study serves as a significant supplement and expansion to the current literature regarding the accepting foreign clinical data policy and innovation, providing crucial empirical support for the further enhancement of the policies to encourage the launch of overseas drugs. It also offers valuable insights for policymakers and R&D decision-makers in the pharmaceutical sector.

2 Institutional background

In China, prior to 2000, overseas drugs with unmet medical demands could be approved without requiring additional clinical trials conducted in China. With the accumulation of R&D and regulatory experience, the regulatory authority began to require Chinese clinical data before marketing approval (7). According to the China Drug Registration Regulation (DRR), a core document governing clinical trials and drug registration issued in 2007, the global pharmaceutical sponsors were required to conduct an additional standalone clinical development program containing pharmacokinetic studies and at least 100 pairs of randomized controlled clinical trials specifically in Chinese patients, even though their drugs had been approved overseas (5, 6). In addition, for overseas new drugs, initiation of phase II/III clinical trials overseas was required for Chinese sites to participate in the MRCTs, and holding marketing authorization in other countries was a prerequisite for applying for marketing in China (5). These local requirements have posed a significant obstacle to approval process of overseas drugs in China. It was reported that during the period from 2004 to 2014, among the 291 new molecular entities approved by the US FDA, only 79 (27%) were approved in China with an average delay of 3 years compared to those in THE US (20). The lag in drug approval has hampered the marketing of overseas drugs and significantly limited their accessibility in China (6).

The above regulations concerning imported drugs in China were not amended for the following decade until 2015. From this year, China initiated a deep reform on the drug review and approval process. The landmark documents of "Opinions of the State Council on Reforming the Review and Approval System for Drugs and Medical Devices" [State Council (2015) No.44] released in August 2015 (21) and "Opinions on Deepening the Reform of Review and Approval System to Encourage Innovation of Drugs and Medical Devices" [State Council (2017) No.42] released in October 2017 (22) proposed to allow simultaneous clinical trials conducted in China and to accept foreign clinical trial data for overseas drugs. In response to these opinions, to facilitate the launch of overseas new drugs and improve patients' accessibility to unmet clinical demand, the former China Food and Drug Administration (CFDA) issued the document "Decisions on the adjustment of imported drug registration [CFDA (2017) No.35]" in October 2017 (8). This document officially permits that early phase clinical trials of imported new drugs can be conducted simultaneously in China and abroad, and abolishes the requirement that imported drugs must obtain marketing authorization in other countries before applying for marketing. In addition, overseas drugs with MRCTs containing Chinese data can apply directly for marketing with the wavier of clinical trial applications. However, this document did not formulate specific implementation measures on how to accept foreign clinical data. Subsequently, in July 2018, the technical guideline on accepting foreign clinical data were formally issued by the National Medical Products Administration (NMPA), which explicitly specifies the principles and requirements on how to accept foreign data, as well as the acceptability of foreign clinical data (9). The guideline emphasizes that depending on the quality, completeness and ethnic sensitivity of the foreign clinical data, the authority may accept the data fully, partially or not at all. In addition, foreign clinical data can be accepted not only from overseas new drugs, but also from overseas generics and biosimilars. In October 2018, the Chinese authority established special approval channels to expedite the review of clinically urgent needed overseas drugs (UNOD) (10). The expedited approval of imported drugs with limited or even no Chinese clinical data if no ethnic differences on the UNOD lists released between 2018 and 2020 illustrates canonically accepting foreign data when recognized with the unmet needs and drug delay in treating severe or life-threatening diseases (23).

3 Literature review

3.1 Studies on the accepting foreign clinical data policy

The current studies on the policy of accepting foreign clinical data have mainly focused on the requirements for foreign data quality, ethnic differences and bridging trials. For example, Harpreet Singh and Richard Pazdur explored the acceptance and challenges of new drug applications based on Chinese clinical trial data in the US, including ethnic representation, comparator therapies and occasional data integrity issues (24). Chang et al. discussed the considerations of ethnic differences and bridging trials for accepting foreign clinical data in the US, EU, Japan, and China (25). In addition, a limited number of scholars have examined the implementation effect of the policy on the Chinese pharmaceutical industry, specifically focusing on aspects such as the quality of clinical trials and the approval speed of new drugs. Jiang et al. posited that this policy not only has the

potential to enhance clinical data standards in accordance with international benchmarks but also reinforces Chinese pharmaceutical firms' emphasis on clinical trial data management (26). Liu et al. believed that the proportion of drugs adopting the MRCT pathway has begun to expand and the gap in drug approval between China and other countries has been remarkably shortened due to the implementation of this policy (7). Luo et al. proposed that the accepting clinical trial data for overseas drugs has greatly boosted enthusiasm for innovative drug development. The initiative has substantially increased the number of IND applications and accelerated the approval process of innovative drugs for marketing in China (12).

Through the systematic review of the literature, it is found that existing academic studies on examining the impact of this policy on innovation within pharmaceutical firms are scarce, especially in terms of quantitative analysis. This gap presents an opportunity for potential contributions.

3.2 The relationship between the accepting foreign clinical data policy and corporate innovation investment

There is a limited number of studies on the impact of the accepting foreign clinical data policy on corporate innovation. Since this policy can promote influx of overseas drugs into China (7, 12), which suggests the influence of this policy on the innovation investment of domestic pharmaceutical firms can be theoretically analyzed through the lens of import competition. In this study, we propose that this policy may affect innovation investment through two primary mechanisms: the marketing competition effect and the technological spillover effect.

As for the marketing competition effect, Schumpeterian growth theory holds that economic growth is primarily driven by quality-improving innovations, and the pursuit of monopoly rents by enterprises serves as a significant incentive for innovation (27). Competition plays a crucial role in innovation activities as it has the potential to diminish monopoly rents (28). On one hand, according to Schumpeter's appropriability argument, import competition diminishes post-innovation rents, such as market share and production scale, thereby reducing ex-ante innovation incentives (27, 29). Empirical evidence supporting this perspective can be found in studies such as those conducted by Autor et al. (30), who discovered that rising competition from imports has compelled American firms to reduce operational expenses in R&D, consequently hindering their innovation activities. Similarly, Liu et al. (31) demonstrated that import competition adversely affects innovation in the Chinese manufacturing sector based on the data on industry tariffs and firm patents. On the other hand, due to heterogeneity among enterprises, industries, and regions, in fact, import competition can also stimulate domestic firms to enhance product differentiation and quality by innovation behaviors for retaining or expanding their market shares (32). This phenomenon, commonly referred to as the escape-competition effect, has found support in numerous empirical studies (33–35). For instance, Bombardini et al. found top firms featured increased R&D expenditures and an increase in market shares following import liberalization (33). Bloom et al. argued that import competition could improve the level of patent output and R&D investment of European countries by freeing up the labor and lowering the opportunity cost of firms to switch technology (36).

In China, the policy of accepting foreign clinical data relaxes the registration restrictions of imported drugs, thereby encouraging international pharmaceutical firms to incorporate China in their global registration strategies and facilitating an accelerated influx of overseas drugs into China (7). Consequently, domestic pharmaceutical firms have to face a stiffer competition from imported drugs. Over the past few decades, Chinese innovation in new drug development has predominantly relied on modifying the molecular structures of foreign original new drugs with existing or potential therapeutic targets and mechanisms without infringing patents, which is commonly called "fast-follow" or imitative innovation (37). The registration barrier for imported drugs led to a prolonged drug lag in approval between China and foreign manufacturing countries, which has greatly benefited Chinese pharmaceutical firms due to the low competition from imported drugs. However, an accelerated influx of overseas drugs into China is narrowing the window of drug lag, which not only poses increasing challenges for domestic new drugs with the "fast-follow" innovation strategy to maintain their pioneer advantages, but also makes it become difficult for domestic new drugs with similar therapeutic targets and indications to imported drugs to qualify for expedited review (18, 38). In recent years, the development of China's pharmaceutical industry has been advancing rapidly under the government guidance, and the potential market opportunities remain substantial (39). To create new market opportunities and reshape their own competitive advantages, Chinese pharmaceutical firms will be compelled by this policy to increase their investment in enhancing the innovation capacity to explore first-in-class drugs or develop new technologies for me-better drugs.

Additionally, regarding the technological spillover effect, it refers to the transmission of knowledge and technological learning that enables latecomers to benefit from the R&D efforts of their peers in closely related technological fields (40, 41). The technological gap theory posits that international disparities in technological capabilities serve as a primary driver of cross-border technology diffusion, wherein less developed countries learn from and imitate advanced technologies from technologically superior countries through trade, thereby catalyzing technological convergence (41). Consequently, imports activities act as a significant channel for domestic firms to access not only tangible technological inputs but also embedded tacit knowledge (42). Domestic industries are able to learn from and assimilate imported advanced technologies, including product processes, designs, and managerial practices, to enhance their innovation capacity and improve their competitiveness through the technological spillover effect (43). Furthermore, they can rapidly accumulate both technology and human capital by reverse-engineering foreign technologies and introducing relative talents, ultimately reducing trial-and-error costs and increasing R&D efficiency (44). A body of literature has demonstrated that import-related technological spillovers, which allow domestic firms to learn and assimilate new technologies from their foreign counterparts, can promote domestic technological innovation (42, 45, 46). Firms will increase their investment in R&D expenditures to effectively absorb and transform these technological spillovers (47). Wang et al. found that the international R&D spillover through inward FDI and imports significantly enhances China's innovation performance (46). Sun et al.

showed with the horizontal or mixed cooperation, corporate R&D investment increases as horizontal spillovers rise (48).

The implementation of accepting foreign clinical data supports China's early participation in MRCTs and paves the way for the development and registration of imported drugs in China. Consequently, there has been a significant increase in the number of imported drugs adopting the MRCT pathway in China (7). On one hand, the increase in MRCTs facilitates the diffusion of advanced clinical technologies (such as innovative study methodologies, digital technologies, electronic equipment), talents and management systems from leading global pharmaceutical firms into China. Chinese pharmaceutical firms have long been criticized for their limited capabilities of clinical studies and poor quality of clinical trials (49). To enhance their R&D efficiency and meet escalating standards for clinical trials, the diffusion will drive increased investment in introducing skilled clinical teams, as well as acquiring advanced technologies and equipment (26). On the other hand, simultaneous or early-stage clinical studies of overseas new drugs conducted in China allow domestic firms to gain valuable insights into cutting-edge product innovations, including therapeutic targets, indications and clinical outcomes. Chinese pharmaceutical firms are transitioning from producing generic drugs to developing innovative drugs (39). To improve their innovative capacity and efficiency, they will increase R&D investment in following these new drugs or exploring first-in-class drugs based on these new therapeutic mechanisms. Additionally, the accelerated listing of original imported drugs enhances access to reference preparations in China, thereby facilitating the development of generic drugs, which can also be regarded as a form of technological spillover. Consequently, there will be an increased investment in the consistency evaluation for generic drugs (14). Based on the above analysis, we propose the following hypothesis:

> *H1*: The policy of accepting foreign clinical data can promote the innovation investment of pharmaceutical firms.

3.3 The moderating effect of absorptive capacity

Absorptive capacity is defined as the ability of an enterprise to recognize the value of new and external information, assimilate it, and apply it to commercial ends (50). As external knowledge serves as a vital source of innovation, absorptive capacity is considered as one of the most significant determinants of a firm's ability to enhance the innovation performance (51). By leveraging the absorptive capacity, firms not only expand their knowledge reservoirs and skill base but also improve their ability to assimilate and operationalize emerging information, ultimately driving technological advancements and enhance innovation outcomes (52). This assertion has been substantiated by numerous previous empirical studies. Sikka argued that a high level of absorptive capacity enhances corporate R&D capabilities, thereby leading to improved corporate innovations (53). Zou et al. posited that a positive relationship exists between corporate absorptive capacity and their innovation performance by using a meta-analysis, and this relationship is more pronounced in the context of incremental innovation compared to radical innovation (54).

Moreover, in order to enhance absorptive capacity and effectively assimilate external knowledge, firms must allocate resources and invest internally, particularly in research and development activities (50). Consequently, absorptive capacity also plays a positive moderating effect on firms' R&D investment. For instance, Veugelers discovered that the external sourcing of knowledge will enhance internal R&D investment only if a firm maintains an adequate level of absorptive capacity (55).

In this study, while the accepting foreign clinical data policy may incentivize pharmaceutical firms to innovate, it is also crucial for them to possess sufficient absorptive capacity to value, assimilate and transform external new knowledge and technologies to innovation outcomes (50). Based on the previous review, firms' absorptive capacity is positively correlated with their innovation performance. Enhanced capabilities in assimilating external knowledge not only predictably improve technological outcomes but also strengthen innovation incentives by demonstrating the tangible returns on R&D investments. Consequently, faced with the accelerated influx of imported drugs, enterprises with strong absorptive capacity will be more inclined to adopt a proactive innovation strategy than those firms with a low level of absorptive capacity. Furthermore, an enterprise with higher absorptive capacity can achieve greater product effectiveness and market value due to its abundance of resources, extensive experiences and diverse R&D activities (43). The desire to assimilate external know-how creates a positive incentive to invest in R&D (55). Thus, the higher the level of knowledge absorptive capacity, the more innovation activities can be stimulated. Additionally, absorptive capacity can partially mitigate the uncertainty caused by the policy changes to some extent, maintain the confidence of firms in R&D and alleviate potential negative effects on firms' innovation investment (56). Based on the above discussion, we expect that the positive effect of the policy of accepting foreign clinical data on corporate innovation investment can be enhanced by corporate absorptive capacity. Therefore, the following hypothesis is proposed:

> *H2*: Absorptive capacity positively moderates the effect of the accepting foreign clinical data policy on innovation investment.

The conceptual framework hypothesized in this study is depicted in Figure 2.

4 Research design

4.1 Sample selection and data sources

Based on the industry classification standard system issued by Shenyin & Wanguo Securities Co., Ltd. in July 2021, we take the firms of chemical pharmacy, traditional Chinese medicine and biologics sub-sectors under the pharmaceutical biology sector listed on the A-share market as the research samples. The main commercial activities of pharmaceutical firms in the other three sub-sectors are pharmaceutical trade, medical devices, and medical services (14). As this study aims to explore the impact of the accepting foreign clinical data policy on the innovation investment of pharmaceutical manufacturers, these samples in these three sub-sectors are excluded. The raw data is collected from the China Stock Market Accounting Research Database (CSMAR, an authoritative database from China) and is further processed as the following principles: (1): firms marked with ST or *ST are excluded, which are subject to delisting risk

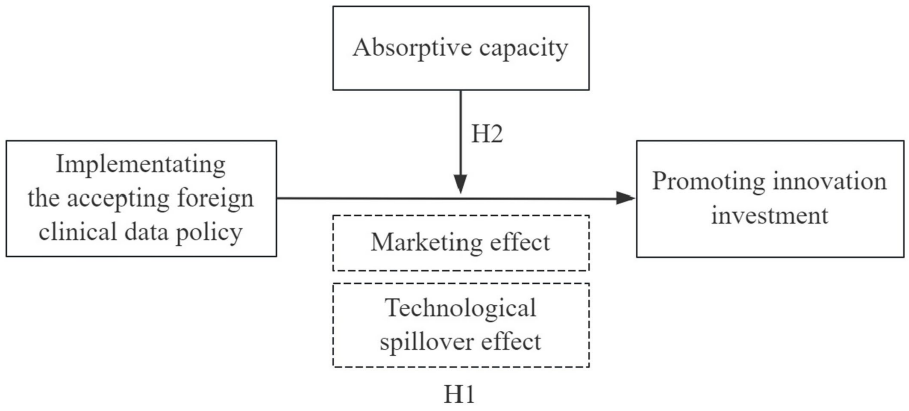


FIGURE 2
Conceptual framework diagram.

warnings; (2) firms with incomplete disclosure of primary data and related indicators are excluded; (3) firms with abnormal data are excluded; (4) firms listed after December 31, 2013 are excluded; (5) In order to mitigate the impact of outliers, all the continuous variables are dealt with by replacing the top and bottom 1% with the value of the observation at 99 and 1% levels. Finally, we obtained the panel data of 104 A-share pharmaceutical listed firms during the period of 2013 ~ 2024 for the empirical analysis, with a total of 1,248 observations.

4.2 Variables

4.2.1 Explained variable

Corporate innovation investment, or R&D investment intensity, is used extensively as a proxy for innovation (13). The higher a firm's innovation investment, the stronger its strategic focus is on innovation, since that the firm has chosen to invest a higher percentage of turnover in innovation activities. Based on previous literature and data availability, we select innovation investment as the explained variable, which is calculated by dividing R&D expenditures by the firm's operating revenue to reduce the impact of firm size on the proxy (13, 14).

4.2.2 Explanatory variable

In October 2017, the CFDA issued the document of "Decisions on the adjustment of imported drug registration [CFDA (2017) No. 35]" to allow simultaneous first-in-human studies tested in Chinese participants for overseas new drugs and direct marketing applications with the MRCTs containing Chinese data, and to remove the requirement that imported drugs must have obtained the marketing approval in other countries before applying for marketing in China, which meant that the Chinese regulatory authority began to accept the clinical trial data conducted outside China (8). Subsequently, in July 2018, the NMPA released the guideline to formally confirm the principles and requirements for accepting foreign clinical trial data (9). Therefore, this study selects the year 2018 as the time point of policy implementation, with *Post* denoting the time dummy variable assigned a value of 1 if *Post* $\geq$ 2018 and 0 if *Post* $<$ 2018.

The acceptance of foreign clinical data relaxes the registration restriction to some extent, which has resulted in an increased rate of registration applications for imported drugs in China. This policy particularly affects the firms engaging in the research of new drugs with the same targets and indications as the imported new drugs, as well as those involved in developing generic drugs or biosimilars of imported drugs (18, 38). Therefore, we sorted out the firms mentioned above as the treatment group from the Drugdataexpy (Chinese phonetic alphabet: Yao Zhi) database built by Chongqing Kangzhou Big Data Co., Ltd., one of the most authoritative platforms providing extensive data services and empowerment in China's medical and health industry, and the remaining firms as the control group. *Treat* represents the group dummy variable, which equals 1 when the firm is in the treatment group, or 0 when the firm is in the control group.

The final core explanatory variable *Treat* × *Post* is measured by the interaction of the treatment group dummy variable *Treat* and time dummy variable *Post* to measure the net impact of this policy.

4.2.3 Control variables

To mitigate the influence of factors other than the core explanatory variable on the explained variable, this study draws upon previous research (13, 14) and selects seven firm-level control variables based on several key dimensions: financial characteristics (asset-liability ratio, cash flow ratio), governance structure (ownership concentration), individual characteristics (size, age) and operating conditions (return on equity, firm's growth ability).

4.2.4 Moderating variable

The accumulation of knowledge and talent is a critical determinant of firms' absorptive capacity (50). Referring to the aforementioned literature (57), we select the proportion of R&D personnel as a measure of absorptive capacity.

The specific definitions of each variable are shown in Table 1.

4.3 Equation design

The DID model can effectively mitigate endogeneity problems among heterogeneous individuals to a large extent by capturing the changes in outcome variables before and after policy implementation (58). In this study, we treat the policy of accepting foreign clinical data as an exogenous shock and construct a DID model to investigate the

TABLE 1 Definition and calculation method of main variables.

Variable type	Variable name	Variable definition	Variable symbol
Explained variable	Innovation investment	R&D expenditures / Operating income (%)	Input
Explanatory variable	*Treat* × *Post*	The interaction term of the group dummy variable and the time dummy variable	DID
Moderating variable	Absorptive capacity	The ratio of R&D personnel (%)	AC
Control variables	Firm size	Ln (total assets)	Size
	Asset-liability ratio	Total debt / Total assets (%)	Lev
	Cash flow ratio	Cash from operating activities / Total assets (%)	Cash
	Return on equity	Net profit / Stockholders' equity balance (%)	Roe
	Firm's growth ability	Operating income growth rate (%)	Growth
	Ownership concentration	The shareholding ratio of the top 10 major shareholder (%)	Shareh10
	Firm's age	Ln (Sample period-establishment period+1)	Age

TABLE 2 Descriptive statistical results.

Variable	Obs	Mean	SD	Min	Median	Max
Input	1,248	6.019	7.167	0.019	4.289	123.019
Size	1,248	22.373	1.003	19.391	22.285	25.489
Lev	1,248	32.404	18.149	1.427	30.134	90.343
Cash	1,248	6.629	6.069	−23.774	6.231	47.063
Roe	1,248	5.985	25.270	−580.143	7.717	66.431
Growth	1,248	11.160	31.351	−65.700	9.255	503.369
Shareh10	1,248	53.478	14.898	18.850	53.003	91.927
Age	1,248	3.044	0.287	1.946	3.091	3.664

impact of this policy on innovation investment of pharmaceutical firms. The baseline regression model is specified as follows:

$$Input_{it} = \alpha + \beta Treat_{it} \times Post_{it} + \theta X_{it} + \lambda_i + \upsilon_t + \varepsilon_{it} \quad (1)$$

In Equation 1, $Input_{it}$ denotes the innovation investment of pharmaceutical firm i in year t. The effect of the accepting foreign clinical data policy is measured by the interaction term $Treat_{it} \times Post_{it}$. A significantly positive estimated coefficient β suggests a positive policy effect on the innovation investment of listed pharmaceutical firms, while a significantly negative coefficient β indicates a negative policy effect. X_{it} represents all the control variables, ε_{it} denotes a random error term, λ_i represents individual fixed effects and υ_t denotes time fixed effects.

5 Results

5.1 Descriptive statistics

Table 2 reports the descriptive statistical findings of the main variables in this study. It can be seen that the innovation investment of pharmaceutical firms in China varies widely, with a minimum value of 0.019, a maximum value of 123.019, and an overall mean of 6.019. This indicates that the innovation investment of Chinese pharmaceutical firms remains at a relatively low level and needs to be further improved. In terms of control variables, according to the mean and standard deviation (SD), the differences in Size and Age among different pharmaceutical firms are minor, while Lev, Cash, Roe, Growth and Shareh10 exhibit significant fluctuations and considerable variability.

5.2 Correlation test

This study conducts the test of the Pearson correlation coefficient matrix for each variable included in the benchmark regression model. According to the results presented in Table 3, the core explanatory variable positively correlates with innovation investment at the 1% significance level, which is consistent with hypothesis 1. In addition, among the paired variables, all the correlation coefficients between DID and control variables are less than 0.5, indicating that there is no serious multicollinearity in the regression model (15).

5.3 Baseline empirical results

This section mainly examines the impact of accepting foreign clinical data on the innovation investment of pharmaceutical firms in China. A multi-collinearity test is conducted firstly to avoid the impact of data covariance on the empirical results. As shown in Table 4, the Variance Inflation Factor (VIF) of each variable is less than 10, which indicates there is no multicollinearity in the regression model (15). The benchmark regression is analyzed by gradually adding control variables to Equation 1 with individual and time fixed effects to

TABLE 3 Results of correlation test.

Variable	Input	DID	Size	Lev	Cash	Roe	Growth	Shareh10	Age
Input	1								
DID	0.277***	1							
Size	−0.003	0.302***	1						
Lev	−0.087***	0.112***	0.197***	1					
Cash	−0.086***	0.069**	0.048*	−0.308***	1				
Roe	−0.104***	−0.022	0.106***	−0.264***	0.235***	1			
Growth	−0.124***	−0.085***	−0.023	−0.061**	0.044	0.173***	1		
Shareh10	0.023	−0.091***	0.162***	−0.163***	0.163***	0.176***	0.193***	1	
Age	−0.039	0.354***	0.441***	0.206***	−0.095***	−0.025	−0.124***	−0.244***	1

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

TABLE 4 Results of covariance test.

Variables	DID	Age	Size	Lev	Shareh10	Roe	Cash	Growth	Mean VIF
VIF	3.73	1.78	1.51	1.29	1.26	1.20	1.20	1.09	1.84

enhance the reliability of the results. All regressions use robust standard errors, and the estimation results are reported in columns (1) ~ (8) of Table 5. It is observed that the estimated coefficients of the core explanatory variable are all significantly positive regardless of whether control variables are included or not, which indicates that implementing the policy of accepting foreign clinical data significantly stimulates innovation investment of Chinese pharmaceutical firms. The finding is consistent with some previous studies that highlight the positive effect of competition on innovation investment by the escape-competition effect and the technological spillover effect (33). For instance, the study conducted by Guo et al. demonstrated that foreign direct investment (FDI) positively promotes domestic investments in Bangladesh, which may be attributed to the technological spillovers (59).

5.4 The moderating effect of absorptive capacity on policy effect

The role of absorptive capacity in promoting innovation was previously held by most scholars (19, 55). According to the theoretical analysis in the previous section, absorptive capacity promotes positively the effect of the accepting foreign clinical data policy on corporate innovation investment. To verify whether this moderating mechanism is valid, we establish the following regression model (51):

$$Input_{it} = \alpha + \beta_1 Treat_{it} \times Post_{it} + \beta_2 AC_{it} + \beta_3 Treat_{it} \times Post_{it} \times AC_{it} + \theta X_{it} + \lambda_i + \upsilon_t + \varepsilon_{it} \quad (2)$$

In Equation 2, AC_{it} represents the absorptive capacity of firm i in year t. The empirical results are reported in columns (9) and (10) of Table 5. The results demonstrate that the coefficients of DID are significantly positive, regardless of whether the interaction term DID×AC is included or not, which further confirms hypothesis 2. Furthermore, the coefficient of the interaction term DID×AC is 0.380, which is significantly positive at the 1% significance level. This indicates absorptive capacity positively moderates the influence of the accepting foreign clinical data policy on innovation investment of pharmaceutical firms.

Figure 3 is presented to further examine the effect of absorptive capacity. We define high and low on a variable as one standard deviation above or below the mean. One can see that the line with high AC has a positive slope while the line with low AC has a slightly negative slope. This suggests that a firm's absorptive capacity can enhance the positive effect of the policy of accepting foreign clinical data on its innovation investment. That is, firms with greater absorptive capacity are more likely to increase innovation investment in the face of the policy shock. The finding is consistent with Li and Vanhaverbeke's study, which has also verified that absorptive capacity may serve as a positive moderator in the relationship between foreign competition and innovation (19). Therefore, hypothesis 2 is supported.

5.5 Parallel trend test

The difference-in-differences method is based on the assumption that the explained variable must meet the assumption of parallel trends prior to the implementation of the policy. This means that the innovation investment of both the treatment group and the control group should exhibit a similar changing trend before the samples are affected by the policy. Therefore, drawing on the previous studies (13, 15), this section employs the following model to test the parallel trend:

$$\mathrm{Input_{it}} = \alpha + \beta_k \sum_{k=-5}^{6} Treat_{it} \times Post_{2018+k} + \theta X_{it} + \lambda_i + \upsilon_t + \varepsilon_{it} \quad (3)$$

In Equation 3, $Post_{2018+k}$ is a dummy variable before and after the policy shock, and k represents time. The estimation result in Figure 4 demonstrates that the confidence interval of all regression coefficients contain 0 and are insignificant within the 90% confidence interval before 2018. Consequently, there is no significant difference in the innovation investment between the treatment and control groups before the implementation of accepting foreign clinical data,

TABLE 5 Baseline empirical results.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Input	Input	Input	Input	Input	Input	Input	Input	Input	Input
DID	2.086***	2.151***	2.145***	2.006***	2.036***	2.090***	2.113***	2.261***	2.504***	1.796***
	(3.03)	(3.04)	(3.04)	(3.21)	(3.34)	(3.41)	(3.47)	(3.63)	(3.07)	(2.94)
Size		−0.707	−0.758	−0.787	−0.361	−0.259	−0.330	−0.157	−1.374	−1.730
		(−0.86)	(−0.90)	(−1.01)	(−0.52)	(−0.37)	(−0.48)	(−0.24)	(−1.33)	(−1.75) *
Lev			0.015	−0.000	−0.020	−0.018	−0.013	−0.017	−0.002	−0.013
			(0.86)	(−0.02)	(−1.42)	(−1.30)	(−0.91)	(−1.16)	(−0.08)	(−0.60)
Cash				−0.180***	−0.141***	−0.138***	−0.134***	−0.125***	−0.156**	−0.146***
				(−3.34)	(−2.96)	(−2.88)	(−2.72)	(−2.73)	(−2.53)	(−2.87)
Roe					−0.086***	−0.075***	−0.076***	−0.079***	−0.065***	−0.063***
					(−4.23)	(−4.02)	(−4.07)	(−4.28)	(−2.88)	(−2.96)
Growth						−0.018***	−0.020***	−0.020***	−0.026**	−0.021**
						(−3.07)	(−3.32)	(−3.28)	(−2.40)	(−2.02)
Shareh10							0.041*	0.054**	0.065*	0.064**
							(1.95)	(2.46)	(1.97)	(2.04)
Age								10.058**	11.752*	3.052
								(2.22)	(1.94)	(0.59)
AC									0.184***	0.176***
									(3.48)	(3.74)
DID×AC										0.380***
										(4.47)
Constant	4.129***	19.513	20.128	22.350	14.320	12.286	11.300	−20.855	−2.285	33.484
	(15.27)	(1.09)	(1.11)	(1.31)	(0.94)	(0.80)	(0.74)	(−1.15)	(−0.09)	(1.26)
Observations	1,248	1,248	1,248	1,248	1,248	1,248	1,248	1,248	1,050	1,050
R-squared	0.7312	0.7325	0.7332	0.7523	0.7691	0.7730	0.7752	0.7800	0.7776	0.8015
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Robust *t*-statistics in parentheses, ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

suggesting that the selected samples in this study pass the parallel trend test. Further analysis in Table 6 shows that the regression coefficients (coeff2018, coeff2020, coeff2021, coeff2022, coeff2023, coeff2024) after the policy occurred increase and are statistically significant, which implies the positive effect of accepting foreign clinical data on the innovation investment has grown over time (14). This indicates that this policy has a long-term dynamic effect.

5.6 Robustness tests

5.6.1 Control other policy effect

To improve the approval efficiency of clinical trials and expedite the launch of new drugs, the latest Drug Administration Law in China, carried out on November 1st, 2019, has transitioned the application procedure for drug clinical trials from the prior approval system to an implicit permission system (60). Under this new system, approval will be granted in 60 working days in absence of comment from the Center for Drug Evaluation (CDE). The implicit permission policy for clinical trials also has the potential to stimulate innovation of pharmaceutical firms, which may interfere with our identification for the effect of accepting foreign clinical data. To exclude this potential influence, referring to Li et al. (61), Equation 1 adds the dummy variable $Post_{60}$ indicating whether a pharmaceutical firm applies for clinical trials after 2018 as a control variable for the robustness test. Column (1) of Table 7 presents the estimated results, which demonstrate that the coefficient of DID is 1.704 at the 1% significance level after introducing the dummy variable $Post_{60}$. This result indicates that the policy of implicit permission for clinical trial applications has little interference with the previous findings, confirming the robustness of our estimated results.

5.6.2 Change the explained variable

Existing studies used the absolute value of R&D expenses or the ratio of R&D expenses to total assets as the explained variable to measure innovation investment (62). To further verify our finding, this study changed the explained variable with these two measures. The results, presented in columns (2) and (3) of Table 7, indicate that the interaction terms are still significantly positive, which are consistent with the previous findings (62).

5.6.3 Placebo test

Tthis study conducts a placebo test to further exclude the influence of other potential unobservable factors on the benchmark regression results. Specifically, we randomly selected the same number of firms from all the samples as the "pseudo-treatment group," and the remaining firms were set as the control group. Under the condition that the time point of the policy remained unchanged, the regression equation was conducted again to estimate the regression coefficients (14, 15). Since the "pseudo-treatment group" is randomly generated, the regression coefficients of the interaction terms will be insignificant. Otherwise, the benchmark regression results from the policy effect will be spurious. To avoid the interference of small-probability events, this study conducted 500 random samplings (13), and the result is presented in Figure 5A. The figure demonstrates the distribution of the estimated coefficients of the interaction term on the X-axis and the *p* values on the Y-axis. It can be observed that the distribution of the estimated coefficients of the 500 randomly generated "pseudo-policy dummy variables" generally follows the normal distribution with values mainly concentrated around zero, significantly deviating from the actual coefficient estimate of 2.261 (the rightmost vertical dotted line) obtained in model (1). Additionally, the *p* values of a majority of randomly generated coefficients exceed 0.1, indicating these coefficients are statistically insignificant. The above analysis reveals that unobservable random factors do not drive the impact of accepting foreign clinical data on innovation investment. The results of the benchmark regression analysis are consequently robust. This finding confirms the causal relationship between this policy and the explained variable.

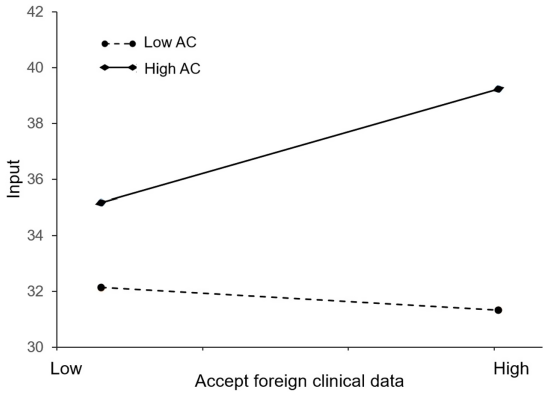


FIGURE 3
Moderating effect of absorptive capacity on the relationship between the accepting foreign clinical data policy and innovation investment of pharmaceutical firms in China.

5.6.4 PSM-DID test

To reduce the self-selection bias of the estimation results owing to the differences in the characteristics of samples between the treatment group and the control group, this study utilizes the propensity score matching DID method (PSM-DID) to verify the impact of accepting foreign clinical data on the innovation investment of pharmaceutical firms (16). Drawing on the previous study, firms in the treatment group are matched with those in the control group based on the propensity score value, which is achieved by the logit regression with control variables as covariates and the dummy variable *Treat* as the explained variable (14). Specifically, this study performs a 1:3 caliper nearest-neighbor matching for the control variables between the control and treatment groups, with the caliper value limited to 0.05. Figure 5B and Table 8 show the differences in covariates of control variables before and after matching. The results indicate that the

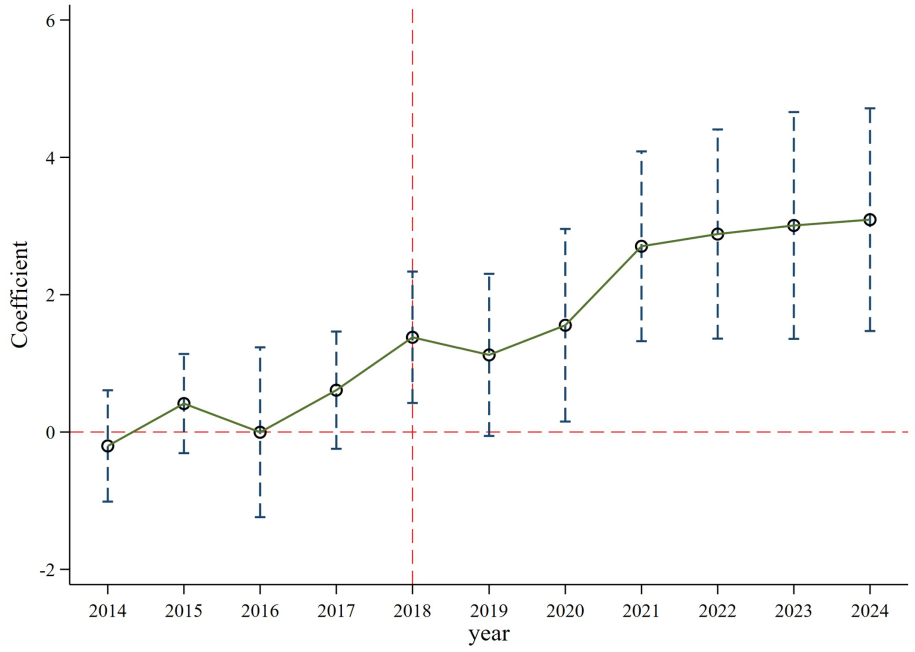


FIGURE 4
Parallel trend test results with control variables.

standardized absolute difference of each control variable is significantly reduced to <10% with p values greater than 0.1 after matching, and the differences in t values between the treatment and control groups are insignificant after matching. Moreover, according to the kernel nuclear density distribution curves of the propensity scores before and after matching in Figure 5C, the difference in the distribution of propensity scores between the treatment and control groups is significantly reduced after matching, suggesting that the data after matching are balanced and the matching is successful. The DID regression results after matching are shown in columns (4) and (5) of Table 7. Furthermore, we also use the kernel matching method and the DID regression results after matching are presented in columns (6) and (7) of Table 7. It is found that the coefficients are still significantly positive, indicating this policy still significantly promotes the innovation investment after matching with two different methods, which is consistent with the original benchmark regression results. The findings confirm the robustness of the benchmark regression results.

TABLE 6 Parallel trend test results.

Variables	Input
coeff2014	−0.203 (−0.42)
coeff2015	0.415 (0.95)
coeff2016	−0.003 (−0.00)
coeff2017	0.609 (1.18)
coeff2018	1.380 ** (2.39)
coeff2019	1.123 (1.58)
coeff2020	1.555* (1.84)
coeff2021	2.705*** (3.25)
coeff2022	2.883*** (3.14)
coeff2023	3.008*** (3.02)
coeff2024	3.093*** (3.17)
Observations	1,248
Control variables	Yes
R-squared	0.7346
Firm FE	YES
Year FE	YES

Robust t-statistics in parentheses, ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

5.7 Heterogeneity analysis

The New-New trade theory highlights that firms in the market differ in size, productivity and organizational structure, which means that not all firms can benefit from import liberalization (63). Therefore, the policy effects on the innovation investment of these different types of firms may not be the same. To ensure the accuracy of the benchmark regression results, it is necessary to discuss the heterogeneity effects of the policy on the listed pharmaceutical firms with different ownership patterns, research objects and market power.

5.7.1 Heterogeneous effects on firms with different ownership patterns

Referring to Liu et al. (15), the sample firms are categorized into state-owned and non-state-owned firms based on the classification criteria from the CSMAR. Subsequently, the baseline regression is conducted within these two groups to analyze the heterogeneous effects of the policy on firms with different ownership patterns. The results presented in columns (1) and (2) of Table 9 indicate that the regression coefficient of this policy on innovation investment in non-state-owned firms is significantly higher at 2.456 compared to state-owned firms with a coefficient of only 0.810, which is not statistically significant. Furthermore, a permutation test reveals that the difference in coefficients between these two groups is significant with the p value less than 0.01. These findings suggest that the policy of accepting foreign clinical data has a stronger impact on innovation investment among non-state-owned pharmaceutical firms compared to the state-owned firms, which is consistent with the heterogeneous effects of the policies including consistency evaluations of generic drugs, price negotiation in medical insurance, and the Marketing Authorization Holder system in previous studies (13, 15, 17).

The different effects of this policy on the state-owned and non-state-owned firms may be attributed to the variances in their organizational structures and management practices (13).

TABLE 7 Robustness test results.

	Input	Input	Input	Input	Input	Input	Input
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
DID	1.704*** (3.18)	0.195** (2.60)	1.188*** (4.78)	2.086*** (3.03)	2.261*** (3.63)	2.059*** (3.14)	2.211*** (3.67)
policy60	1.726*** (2.89)						
Fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Control variables	Yes	Yes	Yes	No	Yes	No	Yes

Robust t-statistics in parentheses, ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

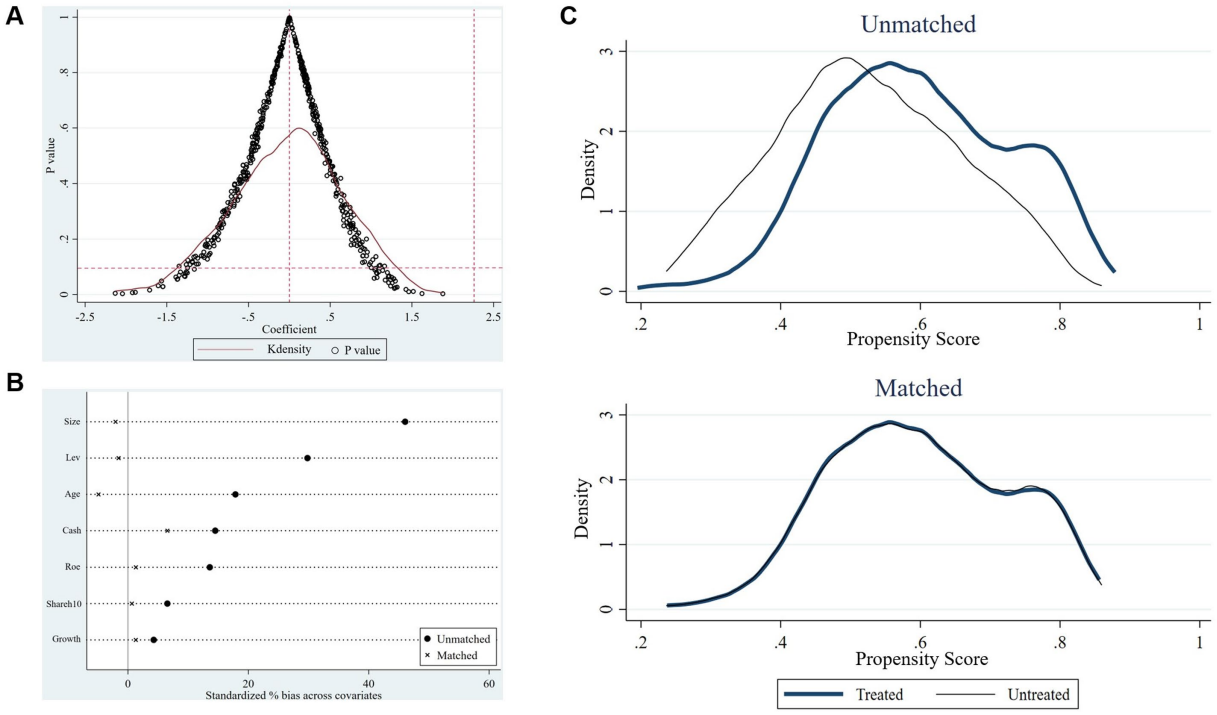


FIGURE 5
The results of robustness tests. **(A)** The result of the placebo test. **(B)** Standardized deviation before and after matching. **(C)** Propensity score distributions for the treatment and control groups before and after matching.

TABLE 8 Propensity score matching (PSM) results.

Variable	Matched	Treated	Control	%bias	%reduct |bias|	t	*P*>|t|	V(T)/V(C)
Size	U	22.566	22.118	46.1		8.13	0.000	0.79*
	M	22.556	22.576	−2.1	95.5	−0.40	0.692	0.81*
Lev	U	34.658	29.373	29.8		5.19	0.000	1.19*
	M	34.595	34.871	−1.6	94.8	−0.27	0.784	0.92
Cash	U	6.9855	6.1399	14.5		2.54	0.011	0.95
	M	6.9796	6.5976	6.6	54.8	1.26	0.206	1.01
Roe	U	7.7377	6.1945	13.6		2.37	0.018	1.13
	M	7.7545	7.606	1.3	90.4	0.25	0.800	1.22*
Growth	U	10.573	9.6043	4.3		0.75	0.455	1.09
	M	10.317	10.023	1.3	69.7	0.26	0.798	1.22*
Shareh10	U	53.895	52.92	6.5		1.15	0.249	0.86*
	M	53.782	53.685	0.6	90.1	0.12	0.905	0.82*
Age	U	3.0662	3.0158	17.9		3.14	0.002	0.86*
	M	3.0649	3.0787	−4.9	72.6	−0.96	0.338	1.04

State-owned firms play a dominant role in the Chinese economy, prioritizing the national overall economic stability and strategic security. Their close ties with the government grant them certain non-market privileges in resource acquisition, leading to a relatively lower incentive for technological innovation and a tendency to avoid high-risk innovative activities (16). However, non-state-owned firms, facing less policy preference and greater competitive pressure, are driven to make full use of innovation assets to maximize capital returns. These firms exhibit a higher degree of flexibility in R&D expenses and demonstrate a stronger motivation to acquire innovative technology for enhancing their competitiveness and improve their market position (15). In response to the increased "invasion" of imported drugs due to the policy of accepting foreign clinical data, non-state-owned firms demonstrate a greater ability than state-owned firms to swiftly and effectively identify and respond to market demands, as well as to invest flexibly in innovations.

TABLE 9 Results of the heterogeneity analysis.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	State-owned	Non-state-owned	New drug	Non-new drug	Strong market power	Weak market power
	Input	Input	Input	Input	Input	Input
DID	0.810	2.456***	2.805***	−0.076	3.600***	0.385
	(1.40)	(3.14)	(3.71)	(−0.14)	(4.10)	(0.76)
Observations	360	888	804	444	684	540
R-squared	0.7513	0.7790	0.8090	0.7374	0.7994	0.7459
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Control variables	YES	YES	YES	YES	YES	YES
Permutation test	−1.646***($p = 0.006$)		−2.882***($p = 0.000$)		−3.215***($p = 0.000$)	

The empirical p values of the coefficient differences between the different groups are obtained using the permutation test with 1,000 bootstrap replications. This formula for the Lerner index is as follows: (Operating Revenue - Operating Costs - Sales Expenses - Administrative Expenses) / Operating Revenue × 100%. Robust t-statistics in parentheses, ***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

5.7.2 Heterogeneous effects on firms with different research objects

In this study, listed pharmaceutical firms are divided into the new drug group and the non-new drug group, depending on whether they are applying for clinical trials or marketing authorization for new drugs in 2018 and beyond. The regression results for the two groups are presented in columns (3) and (4) of Table 9. The findings indicate that the accepting foreign clinical data policy has a significant positive effect on innovation investment with a coefficient of 2.805 in the new drug group, while the regression coefficient −0.076 of DID is not statistically significant in the non-new drug group. These results suggest that the accepting foreign clinical data policy can effectively promote innovation investment for firms engaged in new drug research but has no effect on those not involved in new drug research.

The possible reasons are as follows. First of all, while accepting foreign clinical data for new drugs and bioequivalent data for generic drugs expedites the marketing approval process for imported new and generic drugs in China, it is crucial to note that the primary objective of this policy is to facilitate the market entry of innovative drugs (8). According to the viewpoint of signaling theory, this sends a signal to the entire market that the state encourages the R&D of new drugs, thereby motivating pharmaceutical firms to increase investment in researching new drugs (15). Secondly, it is well known that new drug research is characterized by long cycles and high costs (39). The investment required to develop new drugs far exceeds that needed for generic drugs, making the positive effect of this policy on the new drug group more significant than that on the non-new drug group. Finally, Chinese generic drugs have been criticized for overcapacity and homogenization, leading to fierce internal competition among generic drugs (39). Typically, a single type of drug may be produced by numerous domestic firms, rendering the effect of the influx of imported generic drugs on innovation investment among non-new drug firms relatively insignificant.

5.7.3 Heterogeneous effects on firms with different market power

The Lerner index is commonly utilized to measure the market power of firms through their pricing ability in the market (64). The higher the value, the greater the market power of firms within the industry. In this study the samples are categorized into two groups: firms with weak market power and firms with strong market power, based on the median Lerner index in the samples. We report the subsample estimation results for firms with strong and weak market power in columns (5) and (6) of Table 9. The results reveal that the coefficient of DID for strong market power firms is 3.600, which is significant at the 1% level. In contrast, the coefficient 0.385 of DID for weak market power firms is insignificant. The result of the permutation test also suggests that there is a significant difference between the two groups. These results indicate that the policy of accepting foreign clinical data can promote the innovation investment of strong market power firms but has no pronounced effect on weak market power firms. The finding is consistent with Schumpeter's innovation viewpoint, which posits that firms with substantial monopoly market power have more resources and incentives to innovate (27).

The reason for the differential effects may be that firms with stronger market power have greater capabilities in risk control, overcoming financing constraints, and investing in project innovation (64). This enables them to navigate challenges more effectively and pursue innovative initiatives with greater confidence. In addition, the policy of accepting foreign clinical data facilitates the influx of overseas drugs, especially innovative drugs (8). As competition intensifies from imported drugs alongside the high investment and risks of R&D for new drugs (39), firms with stronger market power are more likely to allocate more resources to the R&D of new drugs in order to maintain their market position.

6 Discussion

In this study we evaluated the theoretical predictions concerning the positive effect of the accepting foreign clinical data policy on corporate innovation investment. The results accords with the theories that highlight how import competition promotes domestic innovation activities (32–34). This also corroborates the findings of Shu and Steinwender that the escape-competition effect overwhelmingly exists at firms in developing countries (65). In addition, we also found that corporate absorptive capacity plays a moderating role in the relationship between this policy and innovation investment. This

finding is consistent with the previous studies suggesting that adequate absorptive capacity is essential for assimilating external technologies (19, 55). In addition, the heterogeneity effect outcomes of this policy can provide targeted insights for policymakers.

6.1 Theoretical implications

This study presents three main theoretical contributions. First, the current literature on the relationship between the policy of accepting foreign clinical data and pharmaceutical firms' innovation is notably sparse. This paper utilizes a difference-in-differences model to reveal, for the first time, a significantly positive impact of this policy on corporate innovation investment based on the marketing effect and technological effect, which addresses the gap in understanding the relationship between the accepting foreign clinical data policy and innovation. Second, we found that the current literature regarding the impact of imports on innovation primarily focuses on analyzing the effects of import quantity and quality, as well as import tariffs (30, 31, 66). This study contributes to the research on how import-related policies influence firm behavior. Third, this study empirically examines the moderating effect of absorptive capacity and explores the heterogeneity of this policy effect from the perspectives of corporate ownership pattern, research object and market power. This expands the theoretical extension space of the research on corporate innovation investment.

6.2 Practical implications

The findings from this study hold important implications for policymakers. In recent years, the Chinese government's policy-making direction has focused on encouraging the introduction of overseas drugs into the domestic market to address clinical needs (22). Our findings show that the accepting foreign clinical policy significantly promotes the incentives of firms to innovate, which provides valuable evidence and support for policymakers to further improve the relevant policies. Additionally, consistent with the findings of previous studies on policy effects (13, 14), this policy has an insignificant impact on state-owned firms, which gives a hint that more targeted incentive policies should be developed for these firms to improve their innovation incentives. Our study also provides valuable insights for R&D decision-makers in the pharmaceutical sector. The findings regarding both the direct effect and the moderating effect suggest that, in response to the intensifying import competition triggered by this policy, domestic firm should retain their innovation incentives and enhance their absorptive capacities to bolster their competitiveness.

7 Conclusions and recommendations

7.1 Conclusion

The policy of accepting foreign clinical data is vital to facilitate the marketing of overseas new drugs and improve drug availability for patients in China. Meanwhile, it also enhances the import competition of domestic pharmaceutical firms and improves their access to new drugs. To examine the impact of this policy on the innovation incentives of Chinese pharmaceutical firms and explore the underlying influencing mechanism, this study regards the accepting foreign clinical data policy as a quasi-natural experiment and empirically analyze its implementation effect on pharmaceutical firms' innovation investment by using the difference-in-differences method. The conclusions are obtained as follows: (1) The policy significantly promotes the innovation investment of Chinese pharmaceutical firms, and the robustness of the empirical results is verified by various methods, including excluding the effect of the implicit permission policy for clinical trial applications, changing the explained variable and utilizing the placebo test method and the PSM-DID method, respectively (2). The absorptive capacity serves as a positive moderator in the relationship between the policy of accepting foreign clinical data and innovation investment of Chinese pharmaceutical firms (3). The policy exhibits heterogeneous impacts on the innovation investment of listed firms due to different ownership patterns, research objects and market power in China, with a significantly positive effect on state-owned firms, new drug firms and strong market power firms, respectively.

7.2 Recommendations

Based on the above conclusions, we propose the following policy implications.

Firstly, the accepting foreign clinical data policy accelerates the entry of imported drugs into China, which stimulates the incentives for innovation among Chinese pharmaceutical firms. It is crucial for the drug regulatory authority to learn from the advanced practices of relevant international systems, refine and improve relevant technical requirements, optimize the approval process of clinical trials and speed up the integration of China's technical guidance system with international general rules in order to promote simultaneous R&D process of overseas new drugs and further accelerate their launch in China.

Secondly, the development of Chinese pharmaceutical innovation industry is currently in a critical transition period. The influx of imported drugs is putting tremendous pressure on domestic new drug firms. In order to mitigate their pressure, It is imperative for the government to provide subsidies, financing support, rewards or technical assistance to firms engaging in R&D for new drugs. These measures will help to reduce their risk and improve their incentive for firms to pursue innovation. Additionally, it is important for the government to take steps to promote the transformation of state-owned firms, stimulate their innovation vitality, and encourage their engagement in innovative activities.

Thirdly, against the backdrop of the accelerating influx of imported drugs into China, it is imperative for Chinese pharmaceutical firms to proactively pursue innovation in order to increase their competitiveness and enhance their resilience against external shocks. On one hand, firms with strong market power should make the most of their own technical experience and resources to drive continuous innovation and facilitate the overall industry's innovation development. On the other hand, firms with weak market power should increase innovation investment, introduce high-tech personnel and advanced equipment, or engage in collaborative R&D to improve their innovation capability and enhance their market position.

Finally, Chinese pharmaceutical firms should focus on enhancing their absorptive capacity by developing a learning organization and fostering an enterprise culture that values continuous learning. It is recommended to establish an internal knowledge management system, as well as organize various cross-departmental activities for knowledge and information sharing in order to facilitate the diffusion and exchange of knowledge within the organization. Furthermore, it is also crucial to pay attention to building network relationships for acquiring and exchanging external knowledge. Such efforts will contribute to enhancing employees' abilities to effectively acquire, assimilate and apply new knowledge, ultimately improving their incentives and capabilities to innovate.

8 Research limitations and future directions

This study has some limitations that can be further improved. First, this study only includes A-share listed pharmaceutical firms as the research samples, resulting in a relatively small sample size for the benchmark regression. This may introduce potential bias into the conclusions drawn from the analysis. Second, due to data availability constraints, innovation output is not analyzed in this study. It is expected that an increase in innovation investment will drive a corresponding increase in the innovation output of the pharmaceutical industry. Future research on the policy impact on innovation outputs (e.g., number of patent applications, sales of new product) will be conducted once sufficient data is acquired.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

MJ: Conceptualization, Data curation, Formal analysis, Software, Writing – Original Draft. JH: Data curation, Software, Writing – review & editing. SW: Methodology, Supervision, Writing – review & editing. YF: Conceptualization, Methodology, Supervision, Writing – review & editing. YC: Methodology, Project administration, Supervision, Validation, Writing – review & editing.

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Research on factors influencing the performance of public health governance in the ethnic areas of Sichuan Province: a study based on the TOE framework

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Introduction: To better improve the performance of public health governance of the government of ethnic areas in Sichuan Province, and to promote the high-quality development of health and health care in the area.

Methods: Qualitative comparative analysis of fuzzy sets and analysis of necessary conditions.

Results: Big data technology, ecological environment and public opinion environment have a significant impact on the public health governance performance of ethnic area governments in Sichuan Province when they play a major role respectively; the synergistic combination of the three conditions of technology, organization and environment is conducive to the improvement of the public health governance performance of ethnic area governments in Sichuan Province.

Suggestions: Develop digital economy; improve ecological environment; strengthen public opinion management; exert synergistic governance effect of technological, organizational and environmental conditions.

KEYWORDS

ethnic areas in Sichuan Province, TOE framework, public health governance, big data technology, synergistic governance effects

1 Introduction

In today's society, the effectiveness of public health governance is directly related to the safety and well-being of the population. In Sichuan Province, a multi-ethnic region, due to the complex geographic environment, the relatively lagging level of economic development, and significant ethnic and cultural differences, the supply of public health services is significantly insufficient, and the capacity of governance needs to be improved. For the government, it is imperative to improve the performance of public health governance. Therefore, this study focuses on the factors influencing the performance of public health governance in the ethnic areas of Sichuan Province, based on the Technology-Organization-Environment (TOE) framework. Through an in-depth analysis of the influence of technological factors (big data technology, technological infrastructure), organizational factors (governmental attention allocation, public health resource allocation), and environmental factors (public opinion environment, ecological environment) on the performance of public health governance, we aim to reveal the underlying patterns and mechanisms. This study seeks to provide the

government with insights into its inherent laws and mechanisms, enabling targeted policy recommendations and practical guidance to improve governance and promote the high-quality development of public health in these ethnic areas.

2 Materials and methods

2.1 Selection of indicators and data sources

2.1.1 Selection of indicators

This study drew on the research of Chinese scholars Zhao et al. (1), and the variables and measurement indicators are shown in Table 1.

2.1.2 Data sources

The data were obtained from the 2021 Sichuan Health Statistics Yearbook, the 2022 Sichuan Statistics Yearbook, the Sichuan Science and Technology Yearbook, the statistical yearbooks of the cities (states) in the ethnic areas of Sichuan Province, the websites of the people's governments of the 60 counties (municipalities and districts) in the ethnic areas of Sichuan Province, microblogs, and other platforms.

2.2 Research methods

2.2.1 Fuzzy-set qualitative comparative analysis (fsQCA)

Qualitative comparative analysis is based on a holistic approach to analyze complex causal problems caused by a variety of factors with the "group effect" and to explore the relationship between conditional grouping and outcome variables by comparing sample cases. Within specific categories, fuzzy-set qualitative comparative analysis (fsQCA) can better solve the problem of degree variation and local attribution, demonstrating clear advantages in solving complex antecedent issues. Therefore, it was the most suitable research method for this study.

2.2.2 Necessary condition analysis (NCA)

NCA is a new method based on complex causality that can calculate the bottleneck criteria for green development more precisely. In this study, effect sizes calculated using two different estimation methods—cap envelope (CE) analysis and cap regression (CR) analysis —were used to validate condition variables in the necessary condition analysis (NCA) method. The validation followed two basic criteria: first, the effect sizes generated by the analysis of their cap functions (d) must be ⩾0.1 and second, the effect sizes from the Monte Carlo simulated permutation test must be significant.

3 Results

3.1 Data calibration

Based on the framework of fsQCA, the public health governance performance of the government in the ethnic areas of Sichuan Province was regarded as the target set, while the six variable indicators affecting this performance were regarded as the conditional set. In this process, each study sample was no longer simply attributed to a variable indicator or outcome but instead possessed an affiliation score within the corresponding set. This technique is known as calibration, where the credibility and precision of research findings are substantially enhanced by introducing external measures to align the variables with these criteria. Relying on previous research, this study deepened the understanding of the factors influencing the performance of public health governance by transforming raw data into fuzzy set affiliation scores with explanatory power through the use of the direct calibration method.

Based on the calibration criteria of Xu et al. (2), and taking into account the actual distributional characteristics of the case data, this study adopted a differentiation strategy to set the calibration anchor points. For conventional continuous variables—such as government public health governance performance, technological infrastructure, public health resources, and government attention allocation—the upper quartile (75%), median (50%), and lower quartile (25%) of the sample data were selected as the thresholds of "fully affiliated," "intersection," and "not affiliated at all," respectively, with reference to the common practice in fsQCA studies within the field of public management. This quantile calibration method can effectively balance the relationship between theoretical expectations and data dispersion. Specifically, when the case data exceed the benchmark level (0.5) used in the same type of city performance assessments, the data are considered to be fully affiliated. Conversely, when the data fall below the conventional safeguard threshold (0.25), they are considered to be fully unaffiliated.

For emerging variables such as big data technology, the anchor point was constructed using the "mean ± standard deviation," which objectively reflects the agglomeration characteristics of technological innovation factors. The thresholds for the ecological environment and public opinion environment variables were set based on the quantitative results of the policy text. Specifically, the calibrated anchor points for the ecological environment variable were "0.7" for full affiliation, "0.5" for intersection, and "0.3" for full non-affiliation. The calibration anchor point for the opinion environment variable were set as follows: "0.7" for fully affiliated, "0.3" as the crossover point, and "0.1" for full non-affiliation. The calibration details for the condition and outcome variables are shown in Table 2.

3.2 Necessity analysis

As shown in Table 3, the effect size levels of the following conditions were all less than 0.1. In addition, their *p*-values were all greater than 0.05, which was not significant. Among them, the significance levels of technological infrastructure, public health resource allocation, and attention allocation were different from those of the other conditions. However, their effect sizes of 0.01 and 0.005, measured using the CE and CR methods, were less than 0.1; therefore, they cannot be considered necessary conditions for the performance of public health governance in the ethnic areas of Sichuan Province. The *p*-values of the other conditions were all 1, which was not significant. Therefore, they cannot be considered necessary conditions for the performance of public health governance in the ethnic areas of Sichuan Province.

The bottleneck level measure of NCA was used to determine the minimum level that an individual antecedent condition needs to reach

TABLE 1 Variable and measurement indicators.

Level one conditions	Level two conditions	Data measurement indicators
Outcome variable	Government performance in public health governance	Based on the concept of government performance, this study referred to Tao et al. (6) measurements of government performance in public health governance. Due to the lack of data sources, similar alternative indicators were chosen. The public health governance performance of local governments in Sichuan Province was measured using the "number of resident populations in each county" and the "successful treatment rate of active TB patients in each county" for the year 2021.
Technical condition	Big data technology	Big data technology relies heavily on infrastructure such as 5G base stations for data transmission, calculation, and analysis, and the two are inseparable. Therefore, this study measured the number of 5G base stations in each county (city and district) as of the end of 2022.
	Technology infrastructure	According to the measurement standard of Tan et al. (7), the level of technical infrastructure construction in the ethnic areas of Sichuan Province was measured by the indicator "per capita Internet broadband access" for each region in 2021.
Organizational conditions	Public health resource allocation	The number of people served by public health resources determines the efficiency of public health services. This was measured by "the ratio of the number of beds in medical institutions to the total population in each region" and "the ratio of the number of staff in public health institutions to the total population." (8) The data were obtained from the 2021 Sichuan Statistical Yearbook and the 2021 Sichuan Health and Sanitation Statistical Yearbook.
	Allocation of government attention	Due to the unavailability of data, this study adopted indicators from other literature to measure the allocation of government attention using the ratio of government public budget input to the total population in each county (city and district) of ethnic areas in Sichuan Province in 2021.
Environmental conditions	Climate of public opinion	Referring to the measurement method of Jiang (9), this study measured the number of Weibo searches containing the keyword "epidemic situation" in counties (cities and districts) of ethnic areas in Sichuan Province from 1 January 2021 to 31 December 2023.
	Ecological environment	Urban greening construction and ecological environmental protection are inseparably related, and they complement and promote each other. In this study, we decided to use the greening coverage of each county to measure the ecological environmental conditions.

within its range of observations to achieve the target value. In this study, three conditions were found to have a bottleneck level for generating the results of the government's public health governance performance in the ethnic areas of Sichuan Province—namely, technological infrastructure, allocation of public health resources, and allocation of government attention—all of which affect the outcome to roughly the same degree. Specifically, when 10 percent of public health governance performance was expected to be achieved, an input level of 0.1 percent was required for each of the three core elements: technological infrastructure, allocation of public health resources, and allocation of government attention. Furthermore, when the performance target was increased to 100 percent, the input levels of the three elements were expected to rise to 1 percent in tandem. The proportionality relationship indicated that these three elements constituted the bottleneck conditions for system enhancement. Meanwhile, big data technology, the public opinion environment, and ecological conditions did not show similar bottleneck constraint characteristics within the framework of this study.

Necessary condition analysis (NCA) focuses on necessary but insufficient individual determinants and their combinations, while qualitative comparative analysis (QCA) focuses on the combined effects of sufficient but unnecessary determinants. Therefore, this study further employed QCA to test the necessary conditions and to determine whether a single condition (including its non-sets) constitutes a necessary condition for the government's public health governance performance. As shown in Table 4, the consistency of the necessity of the single conditions was low (all less than 0.9). This result is consistent with the findings obtained from the NCA, which showed that there are no necessary conditions for producing high levels of local government public health governance performance.

3.3 Sufficiency analysis of the conditional groupings

In the output of fsQCA, we often see three types of solutions: complex solutions, parsimonious solutions, and intermediate solutions. Among them, the intermediate solution is particularly important because it combines the advantages of the other two solutions. If a certain influencing factor appears in both the parsimonious and intermediate solutions, it is considered the core (main) condition, which has a decisive impact on the result. In this study, when setting the thresholds for the solutions, the consistency threshold was set at 0.75 and the frequency threshold was set at 1 to ensure the rigor and reliability of the study, taking into account previous studies and key elements such as sample size.

Table 5 presents the results of the grouping analysis of government public health governance based on six conditions. A total of four groupings were identified, i.e., there were four grouping paths that produced high levels of government public health governance performance in the ethnic areas of Sichuan Province. The level of consistency of both the individual solutions (groupings) and the overall solution was higher than the acceptable minimum standard of 0.75, with the consistency of the overall solution having a value of 0.8066 and the coverage of the overall solution having a value of 0.4010. It can be seen that the four groupings in Table 5 represent

TABLE 2 Calibration of condition and outcome variables.

Level one conditions	Level two conditions	Calibration standards		
		Full affiliation	Intersection point	Completely unaffiliated
Outcome variable	Government performance in public health governance	95.3450	94.9725	91.0700
Technical condition	Big data technology	0.0825	0.0243	−0.0339
	Technology infrastructure	0.3569	0.2773	0.1681
Organizational condition	Public health resource allocation	52.6450	43.8083	31.6975
	Allocation of government attention	2625.5900	2040.0120	1237.0200
Environmental condition	Climate of public opinion	90.000	36.2000	18.1000
	Ecological environment	57.1610	48.6150	36.6970

TABLE 3 Results of NCA.

Prerequisite	Methodologies	Precision	Ceiling zone	Realm	(d)[b]	P[c]
Big data technology	CE	100%	0.000	0.78	0.000	1
	CR	100%	0.000	0.78	0.000	1
Technology infrastructure	CE	100%	0.010	1	0.010	0.167
	CR	100%	0.005	1	0.005	0.168
Public health resource allocation	CE	100%	0.010	1	0.010	0.167
	CR	100%	0.005	1	0.005	0.168
Allocation of government attention	CE	100%	0.010	1	0.010	0.167
	CR	100%	0.005	1	0.005	0.168
Climate of public opinion	CE	100%	0.000	1	0.000	1
	CR	100%	0.000	1	0.000	1
Ecological environment	CE	100%	0.000	1	0.000	1
	CR	100%	0.000	1	0.000	1

a. Calibrated fuzzy set affiliation values. b. 0.0 ≤ d < 0.1: "low level;" 0.1 ≤ d < 0.3: "medium level." c. Permutation test in NCA (permutation test, resampling times = 10,000).

sufficient conditional combinations for high-level government public health governance performance.

Grouping 1 indicates that the presence of big data technology plays a primary role, while technology infrastructure, public health resource allocation, and government attention allocation play a secondary role. For example, Xichang City, Liangshan Prefecture, has vigorously developed big data technology in recent years. At the same time, it built a digital economy industrial park and organized efforts to learn from global experiences in digital economy development. This city also improved technological infrastructure and gradually optimized the allocation of public health resources according to the "14th Five-Year Plan of Medical and Health Care Service System in Xichang City," which has significantly improved the public health governance performance of the government of the region. In this grouping, when big data technology dominated, technological infrastructure, public health resource allocation, and government attention allocation played complementary roles, while other conditions were irrelevant to achieving high levels of government public health governance performance. This grouping had a consistency of 0.7858, a raw coverage value of 0.1153, and a unique coverage value of 0.0647, suggesting that this pathway was able to explain 11.53% of the cases of governmental public health governance in the ethnic areas of Sichuan Province. In addition, only 6.47% of the public health governance cases of the government in the ethnic areas of Sichuan Province could be explained by this path alone.

In grouping 2, the public opinion environment played a major role. In this study, harmonious and positive public opinion environment conditions broke the limitations of technical and organizational conditions in the area and enabled it to achieve a high level of governance performance. For example, Wenchuan County in Aba Prefecture is a city that attracts a lot of attention from the public online, and sudden epidemics and earthquakes pose major challenges for this land. As Wenchuan County attracts the attention of all sectors of society, the government enforces stricter supervision and management of the local public opinion environment, which promotes the proliferation of positive speech, strengthens the cohesion of the local community, and lays the foundation for the effective promotion of public health governance. The grouping had a consistency of 0.8547, a raw coverage value of 0.0836, and a unique coverage value of 0.0505. This indicated that the path was able to explain approximately 8.36% of the public health governance cases of the government in the ethnic areas of Sichuan Province. Moreover, only 5.05% of these cases could be explained by this path alone.

In grouping 3, the presence of an ecological environment played a major role. For example, Jiuzhaigou County in Aba Prefecture has an excellent ecological environment. It is an important ecological barrier and water conservation area in the upper reaches of the Yangtze River. This county has two national nature reserves, one national forest park,

TABLE 4 Results of the NCA for individual conditions.

Conditional variable	High level of public health governance performance		Non-high level of public health governance performance	
	Consistency	Coverage	Consistency	Coverage
Big data technology	0.4059	0.66573	0.4981	0.44933
~Big data technology	0.6524	0.6568	0.6539	0.4472
Technology infrastructure	0.5665	0.5821	0.6164	0.4303
~Technology infrastructure	0.4456	0.6310	0.4013	0.3860
Public health resource allocation	0.5665	0.5821	0.6164	0.4303
~Public health resource allocation	0.4456	0.6310	0.4013	0.3860
Allocation of government attention	0.5665	0.5821	0.6164	0.4303
~Allocation of government attention	0.4456	0.6310	0.4013	0.3860
Climate of public opinion	0.6669	0.6245	0.6588	0.4190
~Climate of public opinion	0.3795	0.6209	0.4096	0.4551
Ecological environment	0.5183	0.5955	0.5406	0.4219
~Ecological environment	0.4968	0.6142	0.4817	0.4045

TABLE 5 Grouping analysis of high-level government public health governance performance.

Conditional configuration	Technology oriented+ organization support	Environment		Environment oriented + technology and organization support
	Configuration 1	Configuration 2	Configuration 3	Configuration 4
Big data technology	●	⊗	⊗	⊗
Technology infrastructure	•	⊗		•
Public health resource allocation	•	⊗	⊗	•
Allocation of government attention	•	⊗	⊗	•
Climate of public opinion	⊗	⊗	●	⊗
Ecological environment	⊗	●	⊗	●
Matrix	0.7858	0.8547	0.7905	0.7990
Original coverage	0.1153	0.0836	0.1598	0.1336
Unique coverage	0.0647	0.0505	0.1363	0.0754
Consistency of solutions	0.8066			
Coverage of solutions	0.4010			

and two provincial nature reserves, and it is the ecological home to many nationally protected wild animals and plants. It has successively succeeded in creating a national "two mountains" practice innovation base, a national ecological civilization construction demonstration base, and a national ecological civilization construction model. It has been successfully established as a national "two mountains" practice innovation base and national ecological civilization construction demonstration county. The favorable ecological environment in the area prevents and reduces the spread of diseases, ensures the quality of life for residents, and reduces the difficulty while improving the efficiency of the government's public health management efforts. The group pattern had a consistency of 0.7905, a raw coverage value of 0.1598, and a unique coverage value of 0.1363. It indicates that the pathway was able to explain approximately 15.98% of the governmental public health governance cases in the ethnic areas of Sichuan Province. Meanwhile, only 13.63% of the governmental public health governance cases could be explained by this path alone.

In grouping 4, the public opinion environment played a primary role, and the presence of technological infrastructure, public health resource allocation, and government attention allocation played a secondary role. For example, the government issued the "Basic Public Health Service Program" and the "Basic Medical Care Performance Evaluation Program" in 2023, which supervise primary healthcare institutions, health service centers, and township health centers that provide basic public health services and basic medical care in the whole county. The programs constantly rectify technological infrastructure and optimize the allocation of public health resources. At the same time, they actively give feedback to the public, which makes the public opinion environment open and transparent and promotes the performance of public health governance. The grouping

had a consistency of 0.799, a raw coverage value of 0.1336, and a unique coverage value of 0.754. This pathway was able to explain approximately 13.36% of the public health governance cases in the ethnic areas in Sichuan Province. In addition, only 7.54% of the government public health governance cases in the ethnic areas of Sichuan Province could be explained by this path alone.

4 Conclusion and recommendations

4.1 Research conclusion

4.1.1 Big data technology, the ecological environment, and the public opinion environment have a significant impact on the performance of the government's public health governance in the ethnic areas of Sichuan Province when they play a major role individually.

The application of big data is associated with the reduction of government information collection and exchange costs, and its fast and accurate information acquisition characteristics can support the improvement of government public health governance. In addition, people living in an environment with fresh air and high vegetation coverage experience better quality of life and a lower risk of illness, which, in turn, reduces the difficulty faced by the government in public health governance. At the same time, in the age of information and technology, positive public opinion guidance can increase public awareness of public health events and encourage citizens to offer suggestions to the government, thereby motivating the government to strengthen public health management. 4.1.2 The synergistic combination of the three conditions of technology, organization, and environment is conducive to the improvement of the performance of the government's public health governance in the ethnic areas of Sichuan Province.

Based on the sufficiency analysis of the conditional groupings, the resulting four groupings can be divided into three governance modes overall: technology-based + organization-based, environment-based, and environment-based + technology and organization-based. Two of these modes function as combinations of multiple conditions. In governance mode one (technology-based + organization-based), technology and organization work in synergy, and the cooperation between big data technology applications and governmental actors facilitates the collection and analysis of information, improves the efficiency of governance, and enables the government to effectively carry out public health governance. Governance mode three (environment-based + technology and organization-based) reflects the synergy among technology, environment, and organization. These three conditions work in synergy. On the basis of a good environment, the role of both technical and organizational conditions can effectively improve public health governance.

4.2 Policy recommendations

4.2.1 Develop a digital economy and expand the application of big data technology

Due to the sparse population and limited resources in ethnic areas, there is an imbalance in the distribution of resource allocation. The application of big data technology can better identify the differentiated needs of different regions, enable the rational allocation of resources, and effectively alleviate the shortage of resources in ethnic areas. At the same time, ethnic areas should accelerate the development of big data platforms for early warning and analysis systems. These platforms should collect and analyze information on potential public health emergencies through multiple channels and, in coordination with the supply and demand dynamics of medical resources, enable timely monitoring and early warnings—ensuring adequate preparation before peak demand periods (3).

4.2.2 Improve the ecological environment and create a beautiful and healthy city

The ecological environment is an important element of environmental conditions, including the rational use and protection of natural resources such as forests, lakes, and grasslands. In the context of public health governance in the ethnic areas of Sichuan Province, a good ecological environment is conducive to improving the quality of life of residents and reducing the spread of diseases. The government of ethnic areas should further establish good ecological advantages, create clean and hygienic urban environments, reduce the rate of disease transmission, avoid the frequent occurrence of sudden public health events, and lay the foundation for the development of high-quality public health governance.

4.2.3 Strengthen public opinion management and build a harmonious public opinion environment

Since the 21st century, public health events such as SARS, influenza, and epidemics have occurred frequently, which not only affect the normal life pattern of society but also have an immeasurable impact on the public's psychological well-being. Whether the government can react quickly and guide public opinion scientifically in the face of public health emergencies has increasingly become an important indicator for judging its performance in public health governance. Therefore, the government of ethnic areas in Sichuan Province should actively address health emergencies. The media should utilize big data to increase the visibility and credibility of official information releases, guide public attitudes and create a favorable public opinion environment.

4.2.4 Integration of regional technical, organizational, and environmental conditions to achieve a synergistic governance effect

Based on the case data from 60 counties (cities and districts) in the ethnic areas of Sichuan Province, it can be seen that only policies that are tailored to local conditions and in line with the actual stage of development can solve the problems and challenges faced in the field of public health governance. At the same time, the use of big data technology, do a good job of health emergency data and information and monitoring and early warning platform docking, information sharing as the main engine to promote the main synergies, connectivity, strengthen the medical and defense information synergy, so as to increase the information sharing between the main body, and to establish a cross-sectoral integrated epidemic prevention and control information platform (5), in order to promote the synergistic combination of the three technology, organization and the environment, to improve the performance of the government's

public health governance. Specifically, municipal departments can be used as guides to implement "one-to-one" financial guidance and coordination. They can jointly formulate plans for the use of funds and, based on the principle of scientific coordination and needs-based allocation, rationally coordinate the input of financial resources for public health. They can reasonably direct financial funds to remote ethnic minority areas according to need, maximizing the effectiveness of public health funding. This aims to maximize the effectiveness of financial resources for public health services and promote technological development and environmental construction in ethnic minority areas, thereby fully leveraging the synergistic effects of various elements of governance.

Although this study strived to be rigorous, the following methodological limitations should be interpreted with caution. First, some core concepts were measured using proxy indicators, such as tuberculosis treatment rate and resident population size, which, although validated in the literature, may still fail to capture the multidimensional features of governance performance. Second, the timeliness and measurement errors in government yearbooks and social media data might have affected the calibration accuracy, although this was mitigated through cross-validation using multiple sources. Finally, although the group analysis based on the cross-sectional data could identify synergistic associations among the variables, it could not conclusively prove causal mechanisms, suggesting that the findings should be treated as exploratory findings rather than deterministic laws. It is recommended that follow-up studies incorporate tracking data and process-tracing methods to further test the dynamic causal pathways underlying improvements in governance effectiveness.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

YS: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. DC: Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft. JZ: Funding acquisition, Project administration, Resources, Writing - review & editing.

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Conflict of interest

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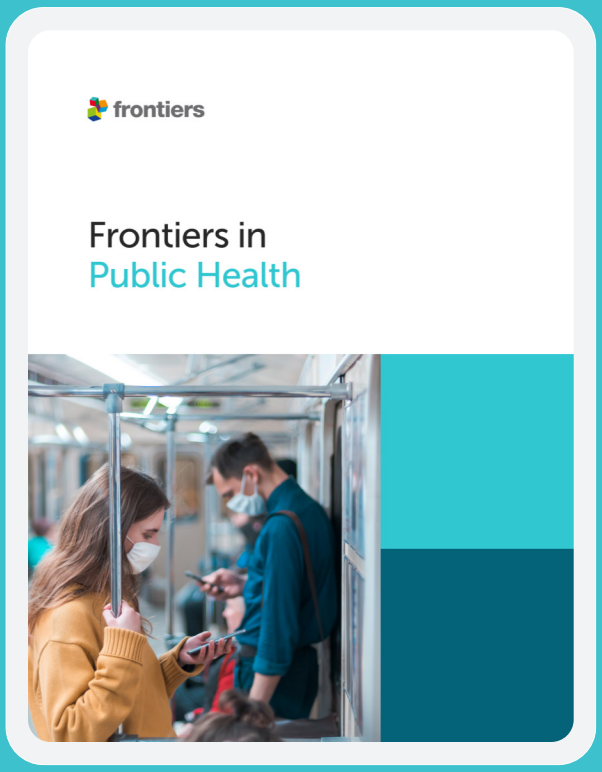
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