frontiers | Research Topics

Creativity, innovation, and entrepreneurship in healthcare and service systems

Edited by
Fu-Sheng Tsai, Gang Li, Xiao-Bing Zhang, Jianhong He and Eugene Mutuc

Published in
Frontiers in Public Health



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ISSN 1664-8714
ISBN 978-2-83251-923-3
DOI 10.3389/978-2-83251-923-3

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Creativity, innovation, and entrepreneurship in healthcare and service systems

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Citation

Tsai, F.-S., Li, G., Zhang, X.-B., He, J., Mutuc, E., eds. (2023). *Creativity, innovation, and entrepreneurship in healthcare and service systems*. Lausanne: Frontiers Media SA. doi: 10.3389/978-2-83251-923-3

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frontiers in Public Health

ORIGINAL RESEARCH
published: 02 July 2021
doi: 10.3389/fpubh.2021.691746

Is Health Contagious?—Based on Empirical Evidence From China Family Panel Studies' Data

Feng Hu[1], *Xiaojiao Shi*[1], *Haiyan Wang*[2], *Nan Nan*[3], *Kui Wang*[4], *Shaobin Wei*[5], *Zhao Li*[6], *Shanshan Jiang*[5], *Hao Hu*[7]* *and Shuang Zhao*[5]

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This study empirically analysed the contagion of health using data from China Family Panel Studies. We first controlled variables related to health behaviour, medical conditions, individual characteristics, household characteristics, group characteristics, and prefecture/county characteristics and then employed multiple methods for estimation. The estimates showed that the average health level of others in the community had a significant positive effect on individual self-rated health—health was contagious. The measurement results remained robust after the endogeneity of the core explanatory variables was controlled using two-stage least squares. Furthermore, by analysing the heterogeneity of health contagion, we found that the contagion effect of health varied with the level of medical care, household affiliation, gender, rural/urban areas, and age groups. The contagion effect of health was more pronounced in the elderly population and the rural areas of the central region, where the level of medical care is relatively low, whereas it did not differ significantly between genders. Finally, the learning or imitation mechanism and social interaction mechanism of health contagion were examined.

Keywords: health, contagion, health in China, self-rated health, contagion mechanism, endogeneity control

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Edited by:
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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *07 April 2021*
Accepted: *07 June 2021*
Published: *02 July 2021*

Citation:
Hu F, Shi X, Wang H, Nan N, Wang K, Wei S, Li Z, Jiang S, Hu H and Zhao S (2021) Is Health Contagious?—Based on Empirical Evidence From China Family Panel Studies' Data. Front. Public Health 9:691746. doi: 10.3389/fpubh.2021.691746

INTRODUCTION

Medical and health services are major issues related to people's health and families' well-being. As an important component of human capital, health is an inevitable requirement for promoting comprehensive human development and a basic condition for economic and social development. In particular, the impact of the COVID-19 outbreak in late 2019 has increased people's awareness of the importance of health and their concern about health issues. Presently, China is vigorously promoting the strategy of constructing a "Healthy China" and has promulgated the "Healthy China 2030" blueprint, which aims to improve the health of all Chinese people by raising the importance of health in the development strategy and prioritising the improvement of people's health.

However, it is also necessary to be aware that the current gap between people's need for a healthy life and the inadequate and imbalanced development of medical and health services remains prominent, which has hindered the improvement of people's health to some extent. Given these circumstances, it is theoretically and practically significant to explore the issue of health contagion.

Numerous factors influence health. For example, many existing studies have analysed the impact of demographic characteristics and socioeconomic factors on health. Regarding demographic characteristics, Banister and Zhang (1) found a gap between female and male health. Similarly, Wagstaff et al. (2) used Chinese Longitudinal Healthy Longevity Survey (CLHLS) data and found that although the health level of the elderly in China improved between 1998 and 2008, health inequalities widened after this period (with the worst health status being seen among the elderly in western regions, the elderly in rural areas, female elderly, and elderly people without spouses). Van Doorslaer and Gerdtham (3) confirmed a significant negative relationship between age and health. In addition, marital status has an impact on individuals' health. Regarding this, Gardner and Oswald (4) argued that marriage could improve individuals' health for two possible reasons. First, married people are inherently healthier than unmarried ones; second, single people are more likely to develop bad habits and be more socially separated than married ones. In addition, Preston (5) found that an increase in income can promote individual health levels; however, the positive effect of absolute income on health decreases as income levels grow. Kools and Knoef (6) argue that only permanent income can affect health levels, and absolute income directly improves individual health levels while also having an indirect impact (7). Grossman (8), Conti et al. (9), and Mueller et al. (10) found that education improves people's health. Additionally, Muurinen (11) put forth the theory of health depreciation, and Fujishiro et al. (12) concluded that occupation is positively associated with self-rated health based on data from the U.S.

In addition, health investment is an important factor that affects health. The impact of health investment on individual health has continued to spike the interest of researchers in China and worldwide. Perrin and Valvona (13) found that increased health investment improves people's health. McClellan et al. (14) and Barnato et al. (15) concluded that intensive treatment resulting from increased health investments significantly reduces people's mortality levels. In developing countries, efficiency and equity may be more important than the scale of government health investment. Zhai et al. (16) found that governments' public health investment could improve the health status of people, and this effect is more obvious for inland areas than coastal provinces, which was also verified by Jiang et al. (17), Zhai et al. (18), and Gallet and Doucouliagos (19). However, Newhouse and Friedlander (20), Wolfe (21), and Tanzi and Schuknecht (22) found that the effects of government health investments are not significant. Fisher et al. (23) also concluded that regions spending more on medical insurance coverage do not achieve better health outcomes than those spending less on the same. Similar results were reported by Chinese researchers in their studies (24). In addition to studying the impacts of health investment on individual health, researchers have also analysed how various social benefits are formed based on health investment influence. Among researchers outside China, Young and Cohen (25) found that patients without medical insurance have a significantly higher post-discharge mortality rate than those with medical insurance. Cohen (26) also concluded that patients without medical insurance are diagnosed with diseases later and have a lower survival rate after curing.

The previously mentioned studies have viewed the health level of an individual as being independent of that of others in the group. However, several studies have found that individuals' behaviour, thoughts, and emotions are easily influenced by the thoughts and behaviours of others (27–30). For example, if the happiness score of an individual's neighbours and friends living nearby increases by one unit, the individual's happiness will increase by 25–34% (31). Further, if the average consumption level of an individual's roommates increases by CNY100, the individual's consumption expenditure will increase by CNY21.5 (32). Researchers often refer to the effects of other people's behaviour, thoughts, or emotions on individual behaviour as neighbourhood effects. Based on this, it is worth asking whether an individual's health—an important indicator of individual well-being—is also influenced by other members of a group. In other words, do neighbourhood effects result in an improvement in the health and well-being for individuals? To date, little research has been conducted to demonstrate the neighbourhood effects of health and its formation mechanism. In fact, in a typical "relational" society like China, the thoughts and behaviour of Chinese residents are easily influenced by those of others due to the strong notion of collectivism. Therefore, we hypothesised that an individual's health level would also be influenced by other members of the group.

Sociologists believe that health behaviours are an intermediate mechanism of health transmission. According to the impact of health behaviours on personal health, individuals are divided into two categories. One category promotes health behaviours, such as regular exercise, intake of a balanced diet, adherence to medications, and obtaining health knowledge. The other encourages health-hazardous behaviours, such as smoking, drinking, staying up late, lack of exercise, and drug abuse. Specifically, we believe that there are two main mechanisms of healthy transmission: learning or imitating mechanisms. Individuals learn or imitate the good health behaviours of the people around them or are imperceptibly influenced by those around them to produce the same or similar health behaviours and then improve their health conditions. For example, other people have the reasonable habit of running, exercising, and collocating nutrition, which may induce us to rationally exercise, run, and arrange nutrition every day. This is a learning or imitation mechanism. This is an active health behaviour. Individuals tend to actively strengthen their investment in health behaviours to improve their health. The second is

the social interaction mechanism. Individuals enrich their health knowledge and improve their health behaviours through information exchanges and discussions with people around them, thereby promoting the improvement of their personal health. Conversely, based on trust and mutual benefit, community members can reach a cooperative network, cultivate others' sense of meaning and goal in life, enhance others' mental health, reduce the impact of stress on others' health, and guide individuals to engage in the behaviour of protecting others' health and their personal health.

The remainder of this paper is organised as follows. Section literature review reviews relevant literature, including studies on neighbourhood effects, peer effects, and health. Section materials and method introduces the research design, including the data sources, variable selection, and model setting. Section analysis of empirical results presents the analysis of empirical results, including the baseline model regression analysis, endogeneity control, robustness test, and heterogeneity analysis. Section analysis of empirical result describes the tests for the two mechanisms of health contagion—the learning or imitation mechanism and the social interaction mechanism. Finally, section limitations and future research dire concludes this paper.

LITERATURE REVIEW

This study is mainly related to three types of literature. One type is regarding the neighbourhood effects. The literature outside China focuses on the impact of neighbourhood effects from four aspects: [1] The impact of neighbourhood effects on adult individuals' health, income, consumption, and poverty. Shouls et al. (33) found that if the poor live in remote areas, their health worsens. By developing a multilevel econometric model, Fang and Zou (34) confirmed that neighbourhood effects are significant in terms of individual poverty, and individuals living in neighbourhoods with higher rates of poverty are more likely to have low income and thus fall into poverty. By exploring whether school poverty is a mediator of neighbourhood effects on students' academic achievement, Wodtke and Parbst (35) found that the impact of school poverty on students' academic achievement is not significant during both childhood and adolescence. [3] Threshold and non-linear characteristics of neighbourhood effects influencing individual social behaviour. Using the unemployment rate as a neighbourhood characteristic, Buck (36) conducted a study using UK household panel data and found a significant non-linear relationship between the probability of unemployment and that of falling into poverty when the proportion of unemployed neighbours exceeds 23–24%. When the neighbourhood poverty rate exceeds 20%, it has a significant effect on individual delinquent behaviour and school dropout behaviour. [4] Impact of neighbourhood effects on individual adolescent behaviour. Nie et al. (37) used a study sample of Chinese children and adolescents (aged 3–18 years) to confirm the significant impact of neighbourhood effects on obesity. They also found that neighbourhood effects are stronger in rural areas, among individuals at the high end of the body mass index (BMI) distribution and among females.

Compared with foreign studies, studies in China remain in their infancy, as they mainly focus on individual and household behaviours, such as gambling participation, stock market participation, household donation activities, household education expenditures, residents' mental health, and individual poverty. Li and Zhou (38) argued that the neighbourhood effects of group members' participation in gambling can raise individuals' gambling participation expectations, while the irregularity of the gambling system reduces the positive role of neighbourhood effects. Many studies have found that neighbourhood effects significantly influence residential stock market participation. By extending the individual stock investment optimisation model, Wang et al. (39) found that family social networks (i.e., those based on ties with family and friends) increase the likelihood of residential stock market participation. Once residents enter the stock market, the shares of their stock holdings in their financial wealth increase. Zhou et al. (40) argued that neighbourhood effects can more significantly drive residents' stock market participation for communities with a high proportion of local goods expenditures and a highly concentrated income distribution. Similarly, Zhu et al. (41) argued that for every 1% increase in the neighbourhood effect indicator, the probability of household participation in the stock market increases by ∼0.2%, and the degree of participation in the stock market increases by ∼0.7%. However, neighbourhood effects have no significant impact on stock market returns. In addition, neighbourhood effects have a significant impact on household donation activities and household education expenditures. Yan et al. (42) concluded that for every 1% increase in the average social donation activity of community groups, the probability of households choosing social donation increases by approximately 0.327% to 0.549%. Other information access channels, such as the Internet, reduce the extent to which neighbourhood effects impact household social donation activities. Yu and Zhan (43) found that for every 1% increase in the average education expenditure of households in the community, household education expenditure increases by ∼0.307%. For rural areas, the widening income gap between middle- and high-income households and between low- and middle-income households make household education expenditure more sensitive to the average education expenditure of other households in the same community. Yao and Jiang (44) found the existence of neighbourhood effects in farms' behaviour and concluded that neighbourhood effects among farms lead to a shift from non-safe production behaviour to safe production behaviour.

Other studies are related to peer effects. This topic has attracted considerable attention and extensive discussion among Western researchers, but relevant research has also been conducted in China. Research on peer effects has been conducted from the perspective that individual behaviours are transmitted through social relationships. However, such studies have mostly focused on a certain group and primarily examine the cluster

effect in education and health, including the influence of peer groups on adolescents' academic achievement, violent behaviour, and reading habits, the influence of roommates in dormitories on college students' social activities, consumption behaviours, career choices, smoking and alcohol abuse, and the influence of peer groups on college graduates' intentions to start a business. For example, Victor and Analía (45) verified the existence of gender-based peer effects by studying students' academic achievement at three different academic levels (elementary, middle, and high school) in Israel. They found that the proportion of female students in a class positively contributed to the class's academic achievement and student-teacher relationships. Jane (46) used data from fourth and fifth graders in public elementary schools in North Carolina to verify that peer effects have a significant impact on academic achievement and that peer effects of lower-achieving students are greater than higher-achieving students. Moreover, the study shows that peer effects only work within the same race (e.g., White students vs. White students, non-White students vs. non-White students) and that peer effects are not significant across races. Daniel et al. (47) used a natural experiment with college roommate assignments to test whether peer effects exist in several behaviours that significantly affect health and well-being, such as alcohol abuse, smoking, illicit drug use, gambling, sexual behaviour, suicidal ideation, and non-suicidal self-harm. The results showed that peer effects exist in alcohol abuse and smoking and that the peer effects of smoking are significant among males but not females; no other evidence indicated the existence of peer effects for the other factors. Cheng (32) also confirmed that peer effects exist in college students' consumption behaviours (such that for every CNY100 increase in the average consumption level of college roommates, a student's consumption expenditure increases by CNY21.50). Dong and Qin (48) focused on 14 colleges and universities in Shaanxi and Chongqing to analyse the impact of peer groups on college graduates' willingness to start a business and the impact mechanism. The results; the study showed that college students have greater intentions to start a business when there are other entrepreneurs in the peer group; the closer the relationship with the entrepreneurs, the greater the effect. Zong and Li (49) found that the presence of bad peers in the class has a significant negative impact on students' academic performance and that the academic achievement of male students, students from poor families, and resident students is more sensitive to bad peers in the class.

The third type focuses on health and factors affecting individual health. Such studies are relatively well-established, especially empirical studies that examine factors affecting individual health in terms of individual micro characteristics and the macro environment. Micro characteristics mainly refer to individual and household characteristics—gender, age, work, educational level, cognitive ability, household wealth level, population size, marital status, and urban/rural affiliation. Studies related to micro characteristics focus on adolescent groups, such as college students and retired elderly people. The macro environment mainly refers to the macroeconomic conditions that affect individual health, such as the economic development level, medical care, fitness facilities, medical insurance, and Internet penetration ratio. Generally, men have better health levels than women; the age depreciation effect of health creates significant health differences among different age groups. Having a spouse can significantly improve the cognitive function and health level of individuals; education can influence individuals' perception of health and related health behaviours. Further, in particular, people with higher educational levels have higher cognitive ability and adaptability and better health knowledge, which tends to result in healthier lifestyles and behavioural choices (9, 50, 51). Internet use also contributes to improving individuals' health by increasing income levels and the likelihood of exercise (52, 53). Medical insurance for urban residents significantly contributes to health improvement among the elderly and low-income and less healthy individuals (54, 55). Individuals with low socioeconomic status are disadvantaged in terms of exposure to and mitigation of stress, longevity gains, risk perceptions, and complementary health behaviours and are more likely to engage in risky health behaviours. However, members of upper social classes are less likely to engage in risky health behaviours and tend to lead healthier lifestyles (56–58).

Although the abovementioned research explored neighbourhood effects, peer effects, and residents' health, it is generally limited to a certain aspect of research, and few studies have been conducted on health contagion. In addition, this literature is only targeted at a certain group of people (e.g., children and adolescents such as students or retired elderly people), thereby failing to consider residents' health in a holistic manner. Furthermore, studies have focused more on subjective health indicators, such as sleep, anxiety, and depression, and lacked comprehensive indicators reflecting individual health status, making it difficult to grasp the relationship between individual health and group health.

Based on this analysis, there is still room for discussion on health contagion. Furthermore, it would be theoretically and practically significant to scientifically summarise whether the individual health of Chinese residents is influenced by group health and the influencing mechanism. In this context, we used the 2018 China Family Panel Studies (CFPS) microdata from the Institute of Social Science Survey (ISSS) of Peking University to systematically analyse the contagion of health.

MATERIALS AND METHODS

Data Sources

This study mainly used the 2018 CFPS microdata from the ISSS of Peking University. The Chinese Social Science Research Center of Peking University was established in September of 2006. It is a data survey platform for Peking University's social sciences and an interdisciplinary platform for Peking University to conduct empirical research on social issues in China. The data currently released by the centre include the CFPS and CHARLS data, and the article uses CFPS 2018 data. Data at the individual, household, and community levels are biennially collected to reflect the changes in China's economy, society, and other aspects. The CFPS focuses on the economic and non-economic welfare of

Chinese residents and many research topics, including economic activities, educational achievements, family relations and family dynamics, population migration, and health. It is a national, large-scale, and multi-disciplinary social tracking survey project.

The CFPS2018 sample covered a total of 25 provinces, municipalities, and autonomous regions, with a sample size of ∼16,000 households in each period. The database contains information on all members of each household and is considered as representative nationwide household survey data. There are four types of questionnaires included within it: one each for communities, households, adults, and children. We mainly used questionnaires for communities, households, and adults for this study. As the three types of questionnaires involve different levels of data, we merged the data using Stata 15. After missing key variable values and invalid individuals were excluded, a sample of 20,371 individuals, 7,735 households, and 1,667 communities were used.

Variable Selection

Explained Variable: Individual Self-Rated Health

There are usually two methods to measure international health levels. One is the self-rating of health level method, which measures the entire health status of a respondent through one question; the other is the comprehensive evaluation method, which simultaneously examines multiple dimensions of health and combines the information of each dimension to generate a comprehensive indicator. In this study, we used the self-rated health level method for the follow-up analysis, as it has good reliability and validity and provides a better picture of people's overall health status compared to objective indicators of disease status (59, 60). Self-rated health was measured by the question "How healthy do you think you are now?" The answers were given on a scale of 1–5, ranging from "unhealthy," "fairly unhealthy," "relatively healthy," "healthy," and "very healthy" (i.e., the higher the rating, the better the health).

Core Explanatory Variable: Average Health Level of the Community

An important core explanatory variable in this study was the health level of others. Given that health contagion is closely related to spatial distance (61–63), we need to specify the range of groups to which households belong when constructing this variable. This range should not be too large or too small. The CFPS2018 survey locations were divided into four levels: province/autonomous region/municipality, county/prefecture, town/street, and neighbourhood/village committee. The interview locations for the survey data are specific to neighbourhood committees, which provide the right locational space to explore the contagion of health in this study. Residents within the same community (including both urban neighbourhood committees and rural villages) meet each other frequently, and each community has a common activity space and activity centre. Within a community, residents are closely connected to each other, and their interactions form a social network. Based on this, we classified households from the same community as one group. In accordance with Nie et al. (37), we adopted the common method of calculating the average health level of others (except the respondent) in the existing literature and defined the average health level based on that of other members of the community (excluding the respondent). The calculation method is expressed as shown in [1].

$$\overline{Health_j} = \frac{1}{N-1}\sum_{j\neq i}^{N-1}(Health_j) \quad (1)$$

where N represents the number of respondents in the community.

Control Variables

Referring to the existing literature, we also added other factors that influence the health status of individuals, as these variables may reduce the omitted variables to some extent. These variables include individual characteristics, household characteristics, group characteristics, health behaviour, and the level of medical conditions. Individual characteristic variables included gender (a 0/1 variable; 1 = male), age, squared term of age, marital status (a 0/1 variable; 1 = married), educational level, and whether the Internet is accessible (a 0/1 variable; 1 = yes). In general, individuals who are married, those with access to the Internet, and those with higher educational levels are more likely to manage their health and have better general health. The Internet also has a positive impact on the health of the residents because Internet use can improve the efficiency of health investment, save medical costs, and obtain better health knowledge and information. Household characteristic variables included household size, household income level, and whether the household is in an urban or rural area (a 0/1 variable; 1 = urban). Community characteristic variables included the average age, average household income, average gender, and average educational level in a community, which can be calculated using Equation (1). Health behaviour variables included smoking (a 0/1 variable; 1 = yes), the number of cigarettes smoked per day, the frequency of exercise[1], whether there had been alcohol abuse in the past month, type of medical insurance,[2] and duration of sleep. Variables that reflect local medical conditions include the level of medical care at the point of visit, satisfaction with medical care conditions[3], and the grade of the hospital visited. Other control variables included a dummy variable for the prefecture or county. The descriptive statistics for the specific variables are presented in **Table 1**.

Statistical Analysis

To analyse the impact of community average health on individual self-evaluation health, we conducted the following two analyses. First, descriptive statistics of all variables are provided, including sample size, mean value, standard deviation, maximum value, and minimum value of variables. Second, the

[1]The frequency is in weeks.

[2]There are four types of medical insurance: urban residents' medical insurance, new rural cooperative medical insurance, publicly funded medical insurance, and supplementary medical insurance.

[3]Very dissatisfied is 1, dissatisfied is 2, generally is 3, relatively satisfied is 4, very satisfied is 5.

TABLE 1 | Definition and descriptive statistics of variables.

Variable type	Variable name	Variable symbol	Sample size	Average value	Standard deviation	Minimum value	Maximum value
Explained variable	Individual self-rated health	Health	20371	2.9748	1.2069	1	5
Core explanatory variables	Average health level of the community	avg_health	20371	2.9748	0.5401	1	5
Health behaviour variables	Whether to smoke	Smoking	20371	0.2814	0.4497	0	1
	Number of cigarettes smoked per day	smoking_s	20371	4.1523	8.3206	0	100
	Frequency of exercise	Exercise	20371	5.4523	2.7987	1	50
	Alcohol abuse in the past month	Drinking	20371	0.1467	0.3538	0	1
	Type of medical insurance	Insurance	20371	9.834	19.843	1	5
	Length of sleep	Sleep	20371	1.9508	3.3384	0	20
Medical condition variables	Level of medical care at the time of visit	medical_level	20371	3.5170	0.8797	1	5
	Satisfaction with medical care conditions	medical_ satisfaction	20371	3.6420	0.8185	1	5
	Grade of hospital visited	medical_place	20371	2.7456	1.5885	1	5
Individual characteristic variables	Gender	Gender	20371	0.5142	0.4998	0	1
	Age	Age	20371	48.870	16.864	16	95
	Squared term of age	age2	20371	2672.658	1627.879	256	9,025
	Marital status	Marry	20371	2.1292	0.8924	1	5
	Educational level	Edu	20371	2.9316	1.3989	1	8
	Access to mobile Internet	Mobile	20371	0.5228	0.4995	0	1
Household characteristic variables	Household size	fml_count	20371	4.2501	2.1321	1	17
	Household income level	Lnfinc	20371	10.682	1.335	0	14.457
	Urban or rural area to which a household belongs	urban	20371	0.5220	0.4995	0	1
Community characteristic variables	Average age in the community	avg_age	20371	48.249	10.382	0	93
	Average household income in the community	avg_lnfinc	20371	10.803	1.5755	0	13.415
	Average gender in the community	avg_gender	20371	0.5192	0.2094	0	1
	Average educational level in the community	avg_edu	20371	2.8792	0.8781	0	7

Source: The data were obtained based on the CFPS2018 data from the ISSS of Peking University.

influence of community average health level on individual self-evaluation health was tested using regression analysis. In the regression, other factors influencing individual health status were added, including individual characteristic variables, family characteristic variables, group characteristic variables, health behaviour variables, medical condition levels, and other control variables. All regressions were performed using a stata/mp 15.0.

MODEL SETTINGS

Setting the Baseline Model

Based on the characteristics of the CFPS2018 cross-sectional data, the following baseline model was constructed to verify the effect of the average health level in the community on individual health:

$$Health_i = \alpha_1 + \alpha_2 \overline{Health_i} + \alpha_3 X_i + \mu_v + \varepsilon_i \quad (2)$$

where $Health_i$ denotes the individual health status; $\overline{Health_i}$ is the average health level of the community; $X_{(i)}$ represents the control variables, including health behaviour variables, medical condition variables, individual characteristic variables, household characteristic variables, and group characteristic variables; μ_v is a dummy variable for prefecture or county; and ε_i is the random disturbance term.

Setting the Mediating Effect Model

To effectively reveal the transmission mechanism of the impact of average health levels in a community on individual health

levels, we set the following recursive model to test the effect of the mediating variable, which is based on the testing method proposed by Zarit et al. (64): ① the effect of the average health level in the community on individual self-rated health was tested; if the coefficient of the average health level in the community was significant, it indicated that the average health level in a community had a significant effect on individuals' self-rated health; ② the effect of an increase in the average health level of the community on the mediating variable was tested; if the coefficient of the average health level in the community was significant, it indicated that the average health level in the community could influence the mediating variable; ③ the mediating variable was added based on step ①; if the effect of the mediating variable was significant, and the coefficient of the average health level in the community became smaller or insignificant relative to the coefficient in step ①, it indicated that the mediating variable had a partial or full mediating effect.

Based on the above test idea, we set the following model for testing:

The first step is to test whether the average health level in a community influences individual self-rated health.

$$Health_i = \alpha_1 + \alpha_2 \overline{Health_i} + \alpha_3 X_i + \mu_v + \varepsilon_i \quad (3)$$

The second step was to test whether the average health level in the community influenced the mediating variable.

$$Intervening_variable_i = \alpha_1 + \alpha_2 \overline{Health_i} + \alpha_3 X_i + \mu_v + \varepsilon_i \quad (4)$$

The third step was to add both the average health level in the community and the mediating variable into the model.

$$Health_i = \alpha_1 + \alpha_2 \overline{Health_i} + Intervening_variable_i + \alpha_3 X_i + \mu_v + \varepsilon_i \quad (5)$$

where $Intervening_variable_i$ is the mediating variable, and the remaining variables have the same meaning as in Equation (2).

ANALYSIS OF EMPIRICAL RESULTS

Baseline Regression Analysis

Table 2 presents the estimates of the effect of average health levels in a community on individual self-rated health, including the estimates of the ordinary least squares (OLS) model and the corresponding cluster standard errors. In particular, column (1) lists the estimates when control variables are added; column (2) lists the estimates when health behaviour variables are controlled; column (3) lists the estimates when health behaviour variables and medical condition variables are controlled; column (4) lists the estimates when health behaviour variables, medical condition variables, and individual characteristic variables are controlled; column (5) lists the estimates when health behaviour variables, medical condition variables, individual characteristic variables, and household characteristic variables are controlled; column (6) lists the estimates when health behaviour variables, medical condition variables, individual characteristic variables, household characteristic variables, and group characteristic variables are controlled. The estimates in columns (1)–(6) show that after a series of characteristic variables were controlled, the parameter estimates of the average household health level in the community were still positive at the 1% significance level. In column (6), for example, each unit increase in the average household health level in the community contributed to a 0.718 unit increase in individual self-rated health. In conclusion, the above stepwise regression results show that an increase in the average health level in the community increased individual self-rated health, thus proving the assertion that health is contagious. This result is consistent with the conclusions of Yang and He (53) and Mueller et al. (10).

The estimates of the control variables are explained in this section. In terms of health behaviour variables, it is clear from the estimates that people who smoke and drink have worse health than those who do not. This is because the coefficient of smoking and drinking is significantly negative, and the more they smoke and drink, the worse their health become. Conversely, regular exercise has a positive effect on individual health and is positive at the 1% level of significance, which indicates that individuals who exercise regularly are healthier. However, notably, healthy individuals are also more likely to exercise. As far as our research is concerned, we do not focus on the causal relationship between the two; therefore, we will not discuss it here. Individuals with medical insurance are healthier than those without medical insurance. It can be observed from the estimates of the medical condition variables that local medical care levels, satisfaction with medical care, and hospital type all have a significant positive effect on individual health. For individual characteristic variables, household characteristic variables, and group characteristic variables, men, individuals with higher educational levels, and individuals with higher household income levels also have a significant positive effect on individual household health. Finally, given the potential endogeneity issues with some of the control variables, we cannot interpret or derive much from the results and economic implications of these variables.

Endogeneity Control

Notably, relying only on baseline OLS regressions may result in potential endogeneity issues. The endogeneity stems from two main sources. On the one hand, there is a potential problem of omitted variables in the model, as there are numerous observable and unobservable factors affecting individual health. Even for observable factors, this study cannot encompass all influences, much less for unobservable factors. The problem of omitted variables may have biassed estimates. On the other hand, reverse causality may exist in the baseline model (i.e., the health status of an individual affects the health level of the group). This is because the health behaviour of an individual affects the health behaviour of other individuals, which makes up the health level of the group other than the household. Therefore, such reverse causality exists. This possible reverse causality would mean that

TABLE 2 | OLS regression results.

Variable	Explained variable: individual self-rated health					
	(1)	(2)	(3)	(4)	(5)	(6)
avg_ health	0.7688*** (0.0147)	0.7368*** (0.0145)	0.7164*** (0.0145)	0.6472*** (0.0141)	0.6427*** (0.0141)	0.7180*** (0.0147)
Smoking		−0.0480* (0.0290)	−0.0527* (0.0289)	0.0080 (0.0295)	0.0149 (0.0294)	0.0170 (0.0292)
smoking_s		0.0008 (0.0015)	0.0014 (0.0015)	−0.0066*** (0.0015)	−0.0062*** (0.0015)	−0.0056*** (0.0014)
Exercise		0.0171*** (0.0028)	0.0183*** (0.0028)	0.0095*** (0.0028)	0.0099*** (0.0028)	0.0080*** (0.0027)
Drinking		−0.1638*** (0.0231)	−0.1650 (0.0230)	−0.2161*** (0.0226)	−0.2074*** (0.0226)	−0.2074*** (0.0225)
Insurance		0.0350*** (0.0046)	0.0443*** (0.0047)	0.0189*** (0.0048)	0.0170*** (0.0050)	0.0145*** (0.0050)
Sleep		0.0498*** (0.0024)	0.0485*** (0.0024)	0.0233*** (0.0024)	0.0232*** (0.0025)	0.0241*** (0.0025)
medical_ level			0.0813*** (0.0109)	0.0848*** (0.0105)	0.0854*** (0.0105)	0.0820*** (0.0104)
medical_ satisfaction			0.0359*** (0.0117)	0.0543*** (0.0112)	0.0555*** (0.0112)	0.0558*** (0.0111)
medical_ place			0.0513*** (0.0050)	0.0475***(0.0049)	0.0500*** (0.0049)	0.0490*** (0.0049)
Gender				0.0472** (0.0189)	0.0515*** (0.0189)	0.0672*** (0.0192)
Age				−0.0458*** (0.0025)	−0.0474*** (0.0025)	−0.0493*** (0.0025)
age2				0.0003*** (0.0000)	0.0003*** (0.0000)	0.0003*** (0.0000)
Marry				−0.0280*** (0.0094)	−0.0239*** (0.0094)	−0.0143 (0.0094)
edu				0.0325*** (0.0069)	0.0241*** (0.0071)	0.0256*** (0.0078)
Mobile				0.0402** (0.0198)	0.0236 (0.0199)	0.0214 (0.0198)
fml_count					0.0037 (0.0037)	0.0055 (0.0037)
lnfinc					0.0529*** (0.0062)	0.0583*** (0.0062)
Urban					−0.0204 (0.0172)	0.0188 (0.0177)
avg_age						0.0159*** (0.0010)
avg_lnfinc						−0.0487*** (0.0077)
avg_gender						−0.1222*** (0.0375)
avg_edu						−0.0050 (0.0136)
_cons	0.6846*** (0.0444)	1.0628*** (0.0506)	0.6010*** (0.0612)	1.7528*** (0.0934)	1.2301*** (0.1100)	0.8670*** (0.1215)
Prefecture/county dummy variable	Yes	Yes	Yes	Yes	Yes	Yes
N	20.371	20.371	20.371	20.371	20.371	20.371
Adj R^2	0.1188	0.1462	0.1554	0.2195	0.2225	0.2330

,, and ***Indicate significance at the 10, 5, and 1% levels, respectively; cluster standard errors at the county and prefecture levels are reported in parentheses.*

the effect of average health levels in a community on individual self-rated health is overestimated.

Several measures were taken to address these two issues. First, we included as many control variables as possible (i.e., health behaviour variables, medical condition variables, individual characteristic variables of the householder, household characteristic variables, group characteristic variables, and a dummy variable for prefecture or county). Second, drawing on Yu and Zhan (43), we used the average well-being of other households living in the same community with the respondent household as an instrumental variable for the average health level of the respondent community and performed a regression using a two-stage least squares (2SLS) model. This measure is reasonable because the average well-being of other households living in the same community with the respondent household reflects the average level of well-being of the residents in the area; it is closely related to the health level of households other than the respondent household. In general, the higher the average health level in the community, the higher the average well-being. Alternatively, the higher the average well-being of the community, the higher its average health. Therefore, we can be sure that there is a correlation between the average health level in the community and the average well-being in the community, satisfying the correlation condition of the instrumental variable. Conversely, the well-being of other households is not directly correlated with the health of the respondent household, thereby satisfying the exogeneity condition of the instrumental variable.

Table 3 presents the estimates of the 2SLS model for instrumental variables. The results of Stage I regression show that the average health in the community was significantly positively correlated with the average well-being in the community, which was consistent with the conclusions of Christakis and Fowler (27) and Polsky et al. (65). Moreover, the F value of the weak instrumental variable was much >10, indicating that the selected instrumental variable was highly correlated with the endogenous explanatory variables. Therefore, the possibility of a weak instrumental variable can be excluded. The results of the Stage II regression show that the coefficients of the

TABLE 3 | 2SLS regression results for instrumental variables.

Variable	Explained variable: individual self-rated health				
	(1)	(2)	(3)	(4)	(5)
avg_health	0.8669*** (0.0618)	0.8248*** (0.0631)	0.8646*** (0.0597)	0.8579*** (0.0595)	0.7930*** (0.0546)
Health behaviour variables	Yes	Yes	Yes	Yes	Yes
Medical condition variables	No	Yes	Yes	Yes	Yes
Individual characteristic variables	No	No	Yes	Yes	Yes
Household characteristic variables	No	No	No	Yes	Yes
Group characteristic variables	No	No	No	No	Yes
Prefecture/county dummy variable	Yes	Yes	Yes	Yes	Yes
	Stage I regression				
Average well-being in the community	0.1294*** (0.0037)	0.1263*** (0.0037)	0.1290*** (0.0037)	0.1294*** (0.0037)	0.1398*** (0.0035)
Stage I F value	188.97	153.06	124.43	107.51	203.82
N	20,371	20,371	20,371	20,371	20,371
Adj R^2	0.0687	0.0759	0.0934	0.0947	0.1929

****Indicate significance at the 1% levels; cluster standard errors at the county and prefecture levels are reported in parentheses.*

average health in a community were all positive (at least at the 1% level of significance), and this remained consistent in the regression results of the baseline model. This indicates that the contagion effect of health remained significant after potential endogeneity issues were overcome using the instrumental variable. Therefore, the average health in the community has a significant effect on individual self-rated health, which implies that health is contagious.

Robustness Tests

The above regression analysis reveals that the average health level in a community has a significant positive effect on individual self-rated health, supporting the assertion that health is contagious. However, this finding needs to be verified with caution. To further test the reliability of the baseline model, we applied two different strategies to analyse the estimation results of the baseline model.

Robustness Test Based on Objective Health Indicators

The health indicator we used in the baseline regressions was respondents' self-rated health, which was provided by respondents based on their responses to health questions. Subsequently, there was a problem with biassed answers, as respondents may have provided answers that did not match their actual health status. For example, if respondents suffer from a certain disease and may not want others to know about their condition for privacy protection, they may provide answers that do not match the reality, resulting in biassed answers and thus affecting the estimation results. To overcome this problem, we replaced the original subjective self-rated health indicators with objective health indicators for the regression analysis. Referring to existing literature, we selected two variables to represent the objective health indicators: "Were you hospitalised due to illness in the past year?" and "total medical expenses." **Table 4** presents the results of the estimation. The estimates in columns (1) and (2) show that the parameter estimates of the average health level were significantly negative after all variables were controlled in turn, which coincided with our expectations. However, the sign was the opposite of the baseline results, as the baseline regression analysis was based on subjective self-rated health with a positive sign. Conversely, objective health indicators reflect actual conditions, and higher average health levels have a negative impact on existing objective health. Hence, the sign was the opposite, which also indirectly verified the robustness of the estimation results of the baseline regression model.

TABLE 4 | Robustness test based on objective health indicators.

Variable	Were you hospitalised due to illness in the past year?	Total medical expenses
	(1)	(2)
avg_health	−0.0512*** (0.0047)	−2016.425*** (223.6289)
Health behaviour variables	Yes	Yes
Medical condition variables	Yes	Yes
Individual characteristic variables	Yes	Yes
Household characteristic variables	Yes	Yes
Group characteristic variables	Yes	Yes
Prefecture/county dummy variable	Yes	Yes
N	20,371	20,371
Adj R^2	0.0908	0.0484

****Indicate significance at the 1% levels; cluster standard errors at the county and prefecture levels are reported in parentheses.*

Robustness Tests Based on Different Estimation Methods

We used an OLS model in the baseline regression because the dependent variable in this study was taken in an ordered manner, and using an OLS model enabled a better estimation of the marginal effects through which effect size could be compared. In this section, we re-estimate the baseline model using both the ordered probit model and the ordered logit model. Notably, that the estimates here were not marginal effects but original coefficients and did not affect our analysis of the results. Our focus was on the direction of the coefficients rather than on their comparability and magnitude. Based on this logic, we re-estimated the baseline model using the two estimation methods described above. **Table 5** reports the results of the estimations. The results show that the average health level in the community still had a significant positive effect on individual self-rated health, thus providing further evidence for the assertion that health is contagious. Therefore, the estimation results of the baseline model are considered reliable.

TABLE 5 | Robustness test for the regression based on ordered probit and ordered logit.

Variable	Ordered probit	Ordered logit
	(1)	(2)
Avg_health	0.7569*** (0.0160)	1.3481*** (0.0280)
Health behaviour variables	Yes	Yes
Medical condition variables	Yes	Yes
Individual characteristic variables	Yes	Yes
Household characteristic variables	Yes	Yes
Group characteristic variables	Yes	Yes
Prefecture/county dummy variable	Yes	Yes
N	20,371	20,371
Pseudo R^2	0.0911	0.0944

****Indicate significance at the 1% levels; cluster standard errors at the county and prefecture levels are reported in parentheses.*

Heterogeneity Analysis

Heterogeneity Between Urban and Rural Areas and Among Eastern, Central, and Western Regions

Owing to the unique urban-rural dual system and the uneven regional development in China, urban/rural areas and eastern, central, and western regions should be treated in different ways when analysing whether health is contagious. In this section, we explore whether health contagion exhibits different characteristics depending on the urban/rural and regional affiliations of households. For this purpose, we divided the study samples into urban and rural samples according to the urban and rural areas to which the samples belong and eastern, central, and western samples according to the regions where the samples are located. **Table 6** presents the estimation results. Based on the estimation results for urban and rural areas, we observed that the coefficient of average health level was positive at the 1% significance level for both urban and rural samples, which indicates that health contagion exists in both urban and rural areas. However, the coefficient for rural samples was greater than that for urban samples ($0.7068 > 0.2587$), indicating that the contagion effect of health is more pronounced in rural areas. From the estimated results for different regions, we found that the estimated coefficients for the average health level in the eastern, central, and western regions were all significantly positive, which indicates that the contagion effect of health is also significant in all regions. Nevertheless, the coefficient values for the central, eastern, and western regions were ranked as $0.7229 > 0.7152 > 0.7047$, respectively. This suggests that the contagion effect of health was strongest in the central region, followed by the eastern region. The contagion effect of health was weakest in the western region. Overall, the contagion effect of health was more pronounced in rural areas of the central region.

TABLE 6 | Regression results for health contagion among urban and rural areas and different regions.

Variable	Explained variable: individual self-rated health				
	Urban areas	Rural areas	Eastern region	Central region	Western region
	(1)	(2)	(3)	(4)	(5)
Avg_health	0.2587*** (0.0173)	0.7068*** (0.0254)	0.7152*** (0.0215)	0.7229*** (0.0273)	0.7047*** (0.0304)
Health behaviour variables	Yes	Yes	Yes	Yes	Yes
Medical condition variables	Yes	Yes	Yes	Yes	Yes
Individual characteristic variables	Yes	Yes	Yes	Yes	Yes
Household characteristic variables	Yes	Yes	Yes	Yes	Yes
Group characteristic variables	Yes	Yes	Yes	Yes	Yes
Prefecture/county dummy variable	Yes	Yes	Yes	Yes	Yes
N	10,634	9,737	8,508	6,000	5,863
Adj R^2	0.2587	0.2181	0.2393	0.2282	0.2368

****Indicate significance at the 1% levels; cluster standard errors at the county and prefecture levels are reported in parentheses.*

TABLE 7 | Regression results for health contagion based on differences in medical care level and gender.

Variable	Explained variable: individual self-rated health			
	High level of medical care	Low level of medical care	Male	Female
	(1)	(2)	(3)	(4)
Avg_health	0.6971*** (0.0205)	0.7339*** (0.0209)	0.7169*** (0.0198)	0.7180*** (0.0218)
Health behaviour variables	Yes	Yes	Yes	Yes
Medical condition variables	Yes	Yes	Yes	Yes
Individual characteristic variables	Yes	Yes	Yes	Yes
Household characteristic variables	Yes	Yes	Yes	Yes
Group characteristic variables	Yes	Yes	Yes	Yes
Prefecture/county dummy variable	Yes	Yes	Yes	Yes
N	11,078	9,293	10,475	9,896
Adj R^2	0.2210	0.2336	0.2376	0.2233

****Indicate significance at the 1% levels; cluster standard errors at the county and prefecture levels are reported in parentheses.*

Heterogeneity by Gender and Medical Care Level

A new study from Macquarie University in Australia found that an unhealthy body type with low fat content is attractive to women; however, for men, a healthy body type with normal body fat content is more attractive. This study aimed to show that men and women have different views of health. Accordingly, health contagion is also likely to reveal differences between men and women. To test this assertion, we divided the study samples into males and females and ran separate regressions to corroborate our assertion. The level of medical care is also an important factor that influences health. In areas with high levels of medical care, the contagion effect of health should be stronger, and people should be more concerned about their health status. Therefore, we also divided the study samples according to the level of medical care and ran separate regressions. **Table 7** reports the results of the estimations. Columns (1) and (2) are estimates based on the level of medical care; columns (3) and (4) are estimates based on gender. The results in columns (1) and (2) show that while the average health level had a significant effect in both areas with high and low levels of medical care, the contagion effect of health was more pronounced in areas with low levels of medical care ($0.7339 > 0.6971$). This was not consistent with our previous assertion. This is because regardless of the high or low level of medical care, people are more concerned about their health status—the concept of health is deeply rooted in their minds. In rural areas, medical supply fails to meet people's medical needs because of the limited medical level. When people suffer from major diseases, they choose to go to better hospitals in cities. Therefore, the contagion effect of health is more obvious in rural areas. From the results in columns (3) and (4), we can see that the contagion effect of health is significant among both males and females, but there is no significant difference between them (0.7169 vs. 0.7180). This indicates that although men and women have different views of health, both are concerned about their health, and there is no real difference in the contagion effect of health.

Analysis by Age

The infectivity of health also shows heterogeneity among different age groups. Generally, compared with teenagers and middle-aged groups, older people focus more on their health and medical care information. To test whether the average health level of the community shows significant differences due to different age groups, we divide the total sample into three sub-samples—under 18 years old, 18–60 years old, and over 60 years old—and perform regressions. The results are listed in **Table 8**. From the estimation results, we found that the parameter estimates of the average health level of the community were significant in the 18–60 and 60-year-old groups, which indicates that healthy infectiousness exists in these two groups. However, judging from the size of the coefficient, the contagion effect of people over 60 years of age is more obvious.

MECHANISM TESTING

Testing Health Learning or the Imitation Mechanism

The health learning or imitation mechanism refers to a person learning from or imitating the positive health behaviour of others or making observations of the behaviours of members of the reference group to change their own health status. The test results of the mediating effect model are presented in **Table 9**. Column (1) lists the test results of the first step, which indicates that the average health level in the community significantly improved the self-rated health of individuals. Column (2) shows the test results of the second step, which indicate that the average health level in the community had a significant effect on the learning or imitation mechanism. Column (3) presents the test results of the third step, which show that the effect of the learning or imitation mechanism on individual self-rated health was significant, thus proving the existence of a mediating effect. Additionally, when the mediating variables were controlled, the coefficients of the

TABLE 8 | Regression results for different age groups of healthy infectiousness.

Variable	Explained variable: Individual self-rated health		
	Under 18	18–60 years old	Over 60 years old
	(1)	(2)	(3)
Avg_health	0.5320 (0.6809)	0.4191* (0.2490)	0.5476** (0.2556)
Health behaviour variables	Yes	Yes	Yes
Medical condition variables	Yes	Yes	Yes
Individual characteristic variables	Yes	Yes	Yes
Household characteristic variables	Yes	Yes	Yes
Group characteristic variables	Yes	Yes	Yes
Prefecture/county dummy variable	Yes	Yes	Yes
N	736	13,290	6,345
Adj R^2	0.2087	0.2534	0.2107

** and **Indicate significance at the 10 and 5 levels, respectively; cluster standard errors at the county and prefecture levels are reported in parentheses.*

TABLE 9 | Test results for the learning or imitation mechanism of health contagion.

Variable	Individual self-rated health	Learning/ imitation mechanism	Individual self-rated health
	(1)	(2)	(3)
Avg_health	0.7059*** (0.0146)	0.6322*** (0.0047)	0.6802*** (0.0167)
Learning/imitation mechanism			0.1408* (0.0755)
Health behaviour variables	Yes	Yes	Yes
Medical condition variables	Yes	Yes	Yes
Individual characteristic variables	Yes	Yes	Yes
Household characteristic variables	Yes	Yes	Yes
Group characteristic variables	Yes	Yes	Yes
Prefecture/county dummy variable	Yes	Yes	Yes
N	20,371	20,371	20,371
Adj R^2	0.2229	0.5196	0.2356
Mechanism identification	The mechanism is effective.		

** and ***Indicate significance at the 10 and 1% levels, respectively; cluster standard errors at the county and prefecture levels are reported in parentheses.*

average health level in the community decreased compared to those in the baseline regression. Therefore, we concluded that the learning or imitation mechanism had a partial mediating effect (15.72%).

Testing the Social Interaction Mechanism of Health Contagion

The social interaction mechanism of health contagion refers to an individual being able to obtain relevant information about health through direct communication and discussion with members of the reference group. We used "favour spending" from the CFPS2018 database as a proxy variable for the social interaction mechanism and tested this mechanism using a mediating effect model. The test results are presented in **Table 10**. The results show that the social interaction mechanism of health contagion was significant because the regression coefficients in columns (2) and (3) of **Table 10** were significant at the 1% level. Thus, health is contagious through the social interaction mechanism, although the contagion effect is relatively small (6.95e-06*0.7246/393.34).

LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

This paper focused on the impact of community average health level on individual self-rated health, and used instrumental variable method to deal with its endogeneity, but the problem of endogeneity hasn't been completely solved. Since our study topic is whether health is contagious, we emphasise the neighbourhood effect of health, that is, the neighbourhood effect of health is used to characterise the infectivity of health. According to the existing research, we calculated the average self-rated health level of the community, used the average self-rated health level of the community as the proxy variable of neighbourhood effect, and took it as the core explanatory variable. Our endogenous treatment is also based on the causal relationship between the average health level of the community and individual self-rated health. However, we also added some health behaviour variables, such as whether to smoke, the amount of smoking, the frequency of exercise, and so on. If only these variables are added into the model as control variables, there will be inevitably causal relationship between them and individual self-rated health. These variables as health habit variables will affect individual self-rated health, on the contrary, individual self-rated health will also affect health habit variables. This paper didn't solve the endogenous problem between health habit variables and individual self-rated health. In the future, we will further explore the impact of health habit variables on individual self-rated health, focusing on the causal relationship between health habits and individual self-rated health, which is the main content of our next paper.

CONCLUSIONS

Based on the CFPS 2018 data, we examined whether health was contagious. We also employed an instrumental variable approach to mitigate the endogeneity caused by measurement error and reverse causation and tested the mechanisms of underlying health contagion. We found that after controlling for health behaviour variables, medical condition variables, individual characteristic variables, household characteristic variables, group

TABLE 10 | Test results on the social interaction mechanism of health contagion.

Variable	Individual self-rated health	Social interaction mechanism	Individual self-rated health
	(1)	(2)	(3)
Avg_health	0.7246*** (0.0152)	393.3439*** (94.1103)	0.7219*** (0.0152)
Social interaction mechanism			6.95e−06*** (1.13e−06)
Health behaviour variables	Yes	Yes	Yes
Medical condition variables	Yes	Yes	Yes
Individual characteristic variables	Yes	Yes	Yes
Household characteristic variables	Yes	Yes	Yes
Group characteristic variables	Yes	Yes	Yes
Prefecture/county dummy variable	Yes	Yes	Yes
N	20,371	20,371	20,371
Adj R^2	0.1557	0.0418	0.1572
Mechanism identification	The mechanism is effective.		

****Indicate significance at the 1% levels; cluster standard errors at the county and prefecture levels are reported in parentheses.*

characteristic variables, and prefecture/county characteristic variables, the parameter estimates for the average health level in the community were positive at the 1% significance level, supporting the assertion that health is contagious. Quantitatively, each unit increase in the average household health level in the community would contribute to a 0.718 unit increase in individual self-rated health. To control for endogeneity, we used the average well-being of other households living in the same community (excluding the respondent household) as an instrumental variable for the average health level in the respondent community, which was consistent with the baseline model. In addition, robustness tests were performed using two different strategies, which yielded results consistent with the baseline model. Furthermore, the heterogeneity analysis showed that the contagion effect of health differed depending on the level of medical care, regional affiliation, gender, rural/urban, and age groups. Specifically, the contagion effect of health was more pronounced in the elderly population and the central rural areas, where the level of medical care was lower, while the difference between genders was not significant. Further research found that the contagion of health was achieved through learning or imitation mechanisms and social interaction mechanisms.

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

All authors undertook research, writing, review tasks throughout this study, read, and agreed to the published version of the manuscript.

FUNDING

This work was supported by the Major Program of the National Social Science Foundation of China (Grant No. 20&ZD124), the National Social Science Foundation of China (Grant Nos. 20BJL040, 19BJL108, and 19BJL185), the National Natural Science Foundation of China (Grant Nos. 71773115, 71973129, 71972170, 72074195, 72072164, and 72072162), the Humanity and Social Science Foundation of Ministry of Education of China (Grant Nos. 19YJA790107 and 18YJA790088), and the Key Program of the Soft Science Foundation of Zhejiang Province, China (Grant No. 2021C25027).

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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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frontiers in Public Health

SYSTEMATIC REVIEW
published: 15 July 2021
doi: 10.3389/fpubh.2021.708321

Effect of Mobile Health Technology on Weight Control in Adolescents and Preteens: A Systematic Review and Meta-Analysis

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OPEN ACCESS

Edited by:
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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: 11 May 2021
Accepted: 21 June 2021
Published: 15 July 2021

Citation:
Yien J-M, Wang H-H, Wang R-H, Chou F-H, Chen K-H and Tsai F-S (2021) Effect of Mobile Health Technology on Weight Control in Adolescents and Preteens: A Systematic Review and Meta-Analysis. Front. Public Health 9:708321. doi: 10.3389/fpubh.2021.708321

Childhood obesity is a crucial public health concern. In recent years, numerous studies have employed mobile health technology applications for weight control in children but obtaining varying effects. We conducted a meta-analysis to discuss the effectiveness of mobile health technology in reducing the body mass index (BMI) of obese children. The standardized mean difference (SMD) in BMI between the intervention and control groups was employed to measure the effect of mobile health technology intervention on weight control. The Comprehensive Meta-Analysis Version 3 software was employed for meta-analysis, and the results are presented in a forest plot. This study included nine randomized control trials, which featured a total of 1,202 participants. The meta-analysis revealed that mobile health technology intervention did not have a significant weight loss effect on subjects with obesity. However, by using ethnicity as a moderating variable for subgroup analysis, we discovered that the BMI of ethnic Chinese groups who received mobile health technology intervention was significantly lower than that of the control group. This effect was not significant in the non-ethnic Chinese subgroup. Therefore, the use of mobile health technology intervention for weight control in ethnic Chinese children resulted in significantly lower BMI in these children; however, the use of mobile health technology intervention for weight control is unsuitable for non-ethnic Chinese children.

Keywords: childhood obesity, overweight, adiposity, digital device, adolescents, preteens

INTRODUCTION

Childhood obesity is a crucial, global health problem that has raised concerns among public health experts. However, the prevalence rate of childhood obesity in recent years has remained unchanged (1). Different from traditional weight loss intervention, which involves face-to-face health education, scholars have endeavored to identify alternate methods to provide enhanced weight loss effects (2, 3). Children and adolescents frequently use mobile health technologies to retrieve information from the Internet and interact with online communities in their daily lives;

therefore, mobile health technologies are a feasible channel for providing health information (4). Recently, mobile health technologies have been applied to manage children's weight and prevent obesity (5). Some scholars have done similar studies before, but the included literature includes non-randomized trials (6). Randomized controlled trials (RCTs) are the inclusion criteria for this study. The database search date is also the most recent; therefore, there is newer discovery in our research.

Due to limited time and resources, health experts cannot timely monitor and support patients in their everyday lives. This limitation can be overcome by the development of self-health management technologies (6). Because technology is commonly used in the daily lives of most people, the use of mobile health technologies for weight control presents advantages of high accessibility and adherence (7). In theory, the use of mobile health technologies for weight control in children is effective; after intervention, real-time feedback can be obtained, which maintains the motivation for weight loss in users (8). Mobile health technology is an acceptable and feasible method for reducing childhood obesity. However, large heterogeneity in research design were found across different studies (9, 10). Therefore, a consensus regarding the efficiency of mobile health technology applications in weight control in children has yet to be reached (11). This may or may not be true. However, it is true that despite the contentions there are many studies demonstrating the effectiveness of these technologies. In fact, some groups have cautiously supported their use as an adjunct to weight management interventions. Therefore, the objective of this study was to examine the effect of mobile health technology on weight control in adolescents and preteens.

METHODS

Search Strategy and Inclusion Criteria

A meta-analysis was conducted to evaluate the weight control effect of mobile health technology on subjects with obesity. The researchers searched the Embase, Medline, Cochrane Library, Web of Science, and ScienceDirect databases for articles on mobile health technology interventions among subjects with obesity. The literature collection period ended in February, 2021; the search methods involved using suitable controlled vocabulary and free-text terms. The keywords used for searching included childhood obesity, pediatric obesity, electronic technology, smartphone, activity tracker, mobile device, mobile application, and fitness tracker. The search syntaxes used are detailed in the **Appendix**. Inclusion criteria include RCTs or comparative experimental research. All searched studies comprised at least two participant groups, namely the intervention group and control group. The target population consisted of children and adolescents with obesity risks. In the included literature, intervention was conducted during the follow-up period by using smartphones, social medial, or follow-up instruments.

The selected studies (including RCTs and review articles) were manually screened to determine their inclusion or exclusion in the final analysis. In the first phase, article titles and abstracts were reviewed, and single-arm studies, case series, and case reports were excluded. In the second phase, the researchers reviewed the entire articles, and exclusion criteria included the following: non-RCTs and studies with participants who were older than 18 years of age, absence of BMI data, studies containing participants with physical disability, and interventions not involving mobile health technology. In addition, childhood obesity caused by drug use or diseases was not included in the scope of this study.

Data Extraction and Quality Assessment

After the selected articles underwent a review by the two reviewers, the researchers used a predetermined format to extract article data, primarily the first authors, study periods, sample sizes, participant characteristics, and intervention contents. The two reviewers independently used the Jadad scale to evaluate the quality of the RCTs (12). Jadad scoring is generated across three dimensions, namely randomization (2 points), blinding (2 points), and withdrawals and dropouts (1 point). The total score ranges from 0 to 5; higher scores indicate higher literature quality (12, 13). If the reviewers' opinions differed, a discussion was held between the reviewers under the coordination of a corresponding author until a consensus was reached.

Data Integration and Analysis

BMI is the most commonly used obesity evaluation index and is used by the World Health Organization (WHO) (14), rendering it suitable for meta-analysis; it consists of simple calculations and easily accessible data (15). BMI mean and standard deviation are viable for statistical analysis. Therefore, we used BMI to evaluate weight loss effects. In particular, we used the postintervention standardized mean differences (SMDs) between the intervention and control groups to evaluate the intervention effect. The 95% confidence interval (CI) of the overall SMD was negative, indicating that the weight loss effect in the intervention group was greater than that in the control group. The Comprehensive Meta-Analysis Version 3 (Biostat, Englewood, NJ, USA) was used for analysis. We used I^2 to assess the degree of heterogeneity among the studies. When $I^2 > 50\%$, the included studies had high heterogeneity (16). The random-effect model was used to compile the SMDs in all selected studies and to further identity variables for subgroup analysis. In addition, Egger's test was used to determine potential publication bias. Statistical significance was set as $p < 0.05$ (17); if p was not significant, the number of the included studies was sufficient for meta-analysis.

RESULTS

Literature Search and Characteristics of Included Studies

The article selection was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (**Figure 1**). A total of 254 citations (97, 83, and 74 from Embase, Medline, and Cochrane Library, respectively) were collected. After exclusion of 55 repeated citations, 199 remained. After a review of the titles and abstracts, 74 unsuitable citations were eliminated. Finally, the researchers reviewed the full text of 125 studies. By applying the exclusion criteria, the researchers excluded 50 non-RCT studies, 20 studies with participants over 18 years old, 26 studies that did not present

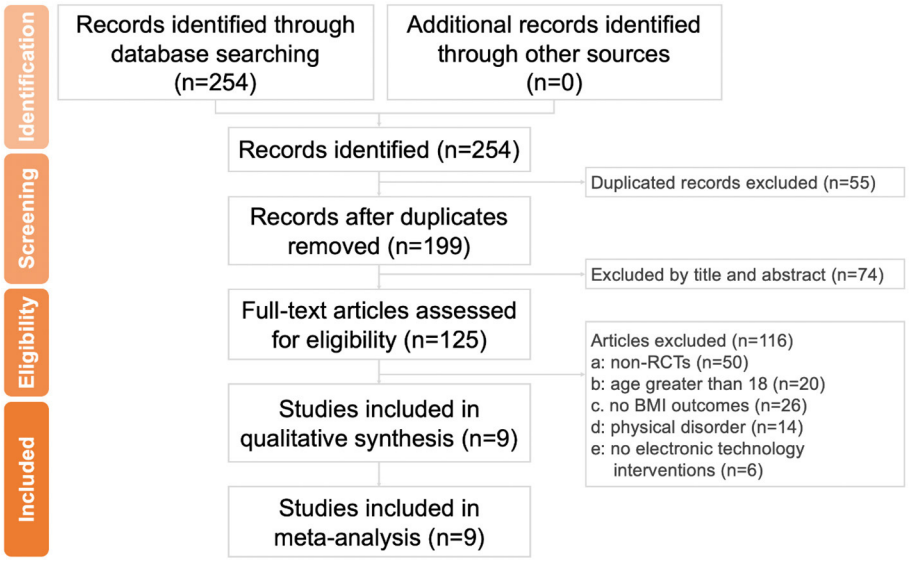


FIGURE 1 | Flow diagram of the study selection process.

their results in terms of BMI, 14 studies in which participants with physical disorders were involved, and 6 studies that did not use mobile health technology inventions. Finally, only 9 double-arm RCT studies were retained for meta-analysis. Regarding participant ethnicity, 3 studies conducted experiments on ethnic Chinese participants from the United States or Hong Kong (18–20) based on sample descriptions of studies; 6 studies were based on non-ethnic Chinese participants from the United States (21, 22), Australia (23–25), and Italy (26).

Finally, 1,202 participants from the included 9 studies were included in the quantified analysis. Overall, the participant age ranged from 8 to 18 years; it ranged from 8 to 18 years for ethnic Chinese participants and 9 to 17 years for non-ethnic Chinese participants. The mobile health technology most often used by the participants included smartphones, wristbands, social media, and short message services, through which participants could engage in weight loss activities and report data. **Table 1** lists the characteristics of the participants, the research method used in each study, and the Jadad scores of the included studies. The table reveals that the Jadad scores of the included studies were all >4, indicating favorable research quality.

SMDs for Weight Control

The meta-analysis included nine studies on weight loss in children. **Figure 2** indicates that the range of 95% CI is shorter and the weighted values are greater for studies with larger sample size. In **Figure 2**, the overall SMD is −0.213 (95% CI: −0.458 to 0.032). The lower and upper limits of the 95% CI of the overall SMD crossed the vertical center line (SMD = 0.00), indicating that the differences between the intervention groups and their corresponding control groups were non-significant. Subsequently, we computed the overall heterogeneity of the 9 included studies; 25, 50, and 75% heterogeneity represented low, moderate, and high heterogeneity, respectively (27). Because I^2 = 72.56%, the studies exhibited high heterogeneity; therefore, identifying moderating variables for subgroup analysis is necessary. After carefully reviewing these nine studies, there seemed to be a discrepancy in effect on BMI between ethnic Chinese and non-ethnic Chinese subgroups. Therefore, we computed the heterogeneity levels between ethnic Chinese and non-ethnic Chinese participant groups and obtained results of I^2 < 0.01% and I^2 = 1.73%, respectively. This indicates that both subgroups exhibited low heterogeneity, thereby verifying that ethnicity is a suitable variable for subgroup analysis. The analysis results in **Figure 3** show that the 95% CI of the overall SMD in the ethnic Chinese subgroup was situated to the left of the center line and did not cross it. This indicates that in the ethnic Chinese subgroup, the decrease in BMI in the intervention groups was significantly higher than that in the control groups (SMD: −0.773; 95% CI: −1.069 to −0.476). In addition, **Figure 4** indicates that the weight loss effect was not significantly different between the intervention and control groups of the non-ethnic Chinese participants (SMD: 0.019; 95% CI: −0.106 to 0.145). Regarding the publication bias of the overall SMD, the results of Egger's test did not exhibit significance (p = 0.146), thereby indicating that publication bias was not present and that the number of included studies was sufficient for the meta-analysis.

DISCUSSION

This study conducted a meta-analysis to determine the effect of mobile health technology application intervention on weight loss in children. The meta-analysis included 3 and 6 studies on experiments conducted with ethnic Chinese and non-ethnic Chinese participants, respectively. The meta-analysis results indicated that mobile health

TABLE 1 | Characteristics of the studies included.

First author, year	Country	Ethnicity	Age	*N* INT/CTR	Intervention (duration)	Study duration (months)	Jadad score
Chen et al. (18)	USA	Ethnic Chinese	13–18	23/17	• Wristband: healthy lifestyle behavior tracking (6 months) • Smartphone and computer: online educational program (3-month intervention phase) • Mobile phone: text messages (3-month maintenance phase)	6	5
Chen et al. (19)	USA	Ethnic Chinese	13–18	21/15	• Wearable sensor: healthy lifestyle behavior tracking (6 months) • Smartphone and computer: online educational modules (3 months) • Mobile phone: text messages (3 months)	6	4
Lee et al. (20)	Hong Kong	Ethnic Chinese	8–16	63/52	• Facebook, apps, email, and phone call: social support (6 months)	6	5
Lubans et al. (21)	Australia	Non-ethnic Chinese	12–14	141/153	• Pedometer: self-monitoring of physical activity (12 months) • Text message: social support (12 months)	12	5
Lubans et al. (22)	Australia	Non-ethnic Chinese	12–14	121/143	• Pedometer: physical activity self-monitoring (17 weeks) • Smartphone apps: screen-time reduction (15 weeks)	18	5
Mameli et al. (23)	Italy	Nonethnic Chinese	10–17	16/14	• Wristband: low energy expenditure (3 months) • Smartphone apps: high energy intake (3 months)	3	4
Nguyeen et al. (24)	Australia	Non-ethnic Chinese	13–16	43/50	• Landline telephone: telephonic coaching (24 months) • Mobile phone: telephonic coaching, short message service and/or email communication (24 months)	24	4
Nollen et al. (25)	USA	Non-ethnic Chinese	9–14	19/18	• Smartphone and tablet: real-time goal setting, self-monitoring, tips, and feedback (3 months)	3	4
Smith et al. (26)	USA	Non-ethnic Chinese	12–14	139/154	• Smartphone apps and website: physical activity monitoring, result recording, tailored messaging, peer assessment, and goal setting (15 weeks) • Pedometer: self-monitoring and goal setting (17 weeks)	8	5

N, Number of participants; INT, Intervention; CTR, Control.

technology intervention did not have a significant effect on weight loss in children. However, when ethnicity was set as the variable for subgroup analysis, the BMI value in the ethnic Chinese intervention group was lower than that in the ethnic Chinese control group, thereby indicating a significantly greater weight loss effect in the ethnic Chinese intervention group. However, for non-ethnic Chinese participants, the intervention effect was not significant. This indicates that the weight loss intervention may consist of underlying mechanisms unrelated to mobile health technology intervention. We speculate that the intervention effects differed between ethnic Chinese subgroup and non-ethnic Chinese subgroup may be due to cultural factors, psychological factors, and the studies on ethnic Chinese participants having shorter follow-up periods than that of studies on non-Chinese participants.

From a cultural factor perspective, a possible mechanism that influences the intervention effect among ethnicity cultures is differences in body image and aesthetic perception (28). Differences in ethnicity culture result in different perceptions toward different body shapes. This factor may result in different obesity prevalence rates among different ethnicities (29). Ethnic Asian students in the United States exhibited high dissatisfaction toward their body image (30). Ethnic Chinese and non-ethnic Chinese adolescents had different psychological feelings toward body weight. Ethnic Chinese adolescents tended to be dissatisfied with their body weights and feel depressed; this phenomenon was not present in Hispanic adolescents (31). This may be the

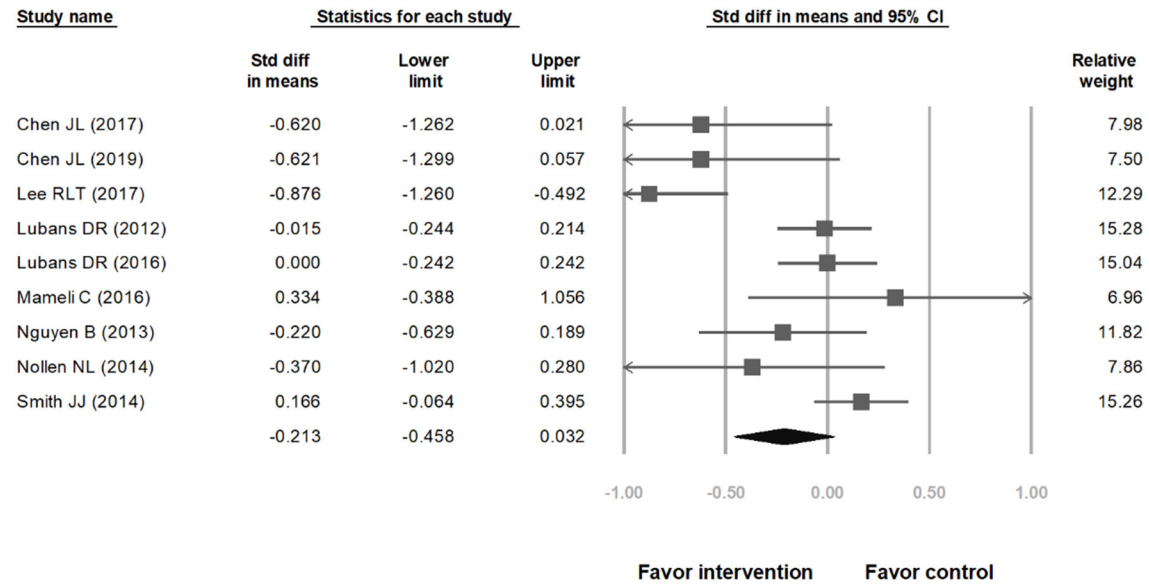


FIGURE 2 | Forest plot showing the effect of mobile health technology on weight control in adolescents and preteens as compared with control groups, overall effect.

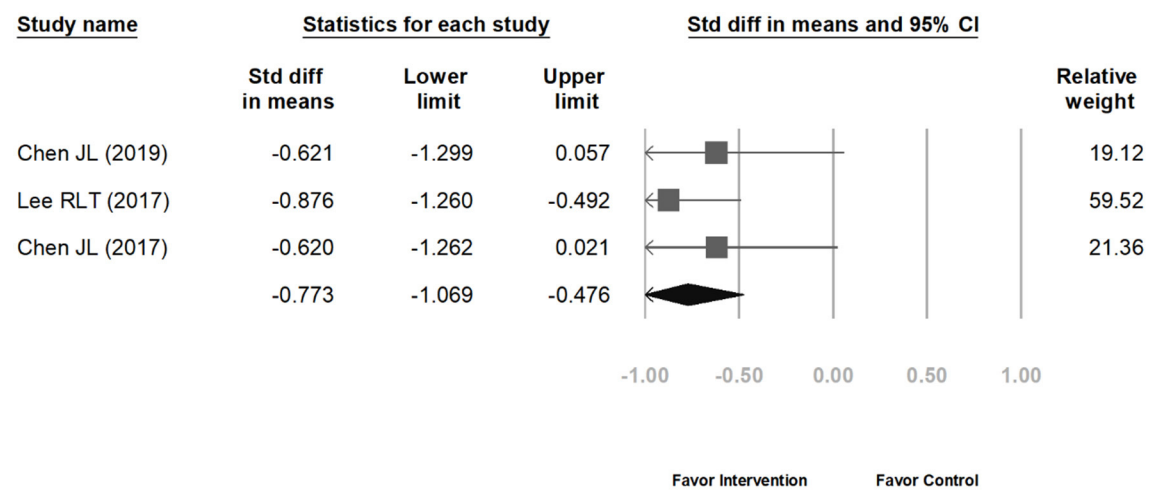


FIGURE 3 | The weight loss effect between the intervention and control groups of the ethnic Chinese participants.

reason underlying the greater weight loss effect of mobile health technology intervention on ethnic Chinese children.

Unhealthy lifestyle is the main cause of obesity. The loss of motivation to live a healthy lifestyle results in an unbalanced diet and sedentary behavior among individuals (32). Maintaining a healthy body weight requires continuous effort; mobile health technology intervention is suitable for enhancing adolescents' motivation to maintain a regular diet and exercise habits (30). This indicates that in addition to the varying acceptance levels of different ethnicity groups toward mobile health technology intervention, differences in psychological factors among different ethnicities may result in varying weight loss effects (33, 34).

One of the important aspects of these technologies is not only that they are based on the evidence and that they support self-monitoring and goal setting, but that they also provide a sufficient amount or dose of "change talk"—that is motivational cognitive challenges that assist the adolescent in making changes in their behavioral choices and weight related decisions with the knowledge and experience that they inherently have and accrue through the intervention.

In addition, differences in the follow-up period in each study may have resulted in the significantly different temporal effects of weight loss (35). The follow-up period of the 3 studies conducted on ethnic Chinese participants was 6 months, whereas among the 6 studies conducted on non-ethnic Chinese participants, 4

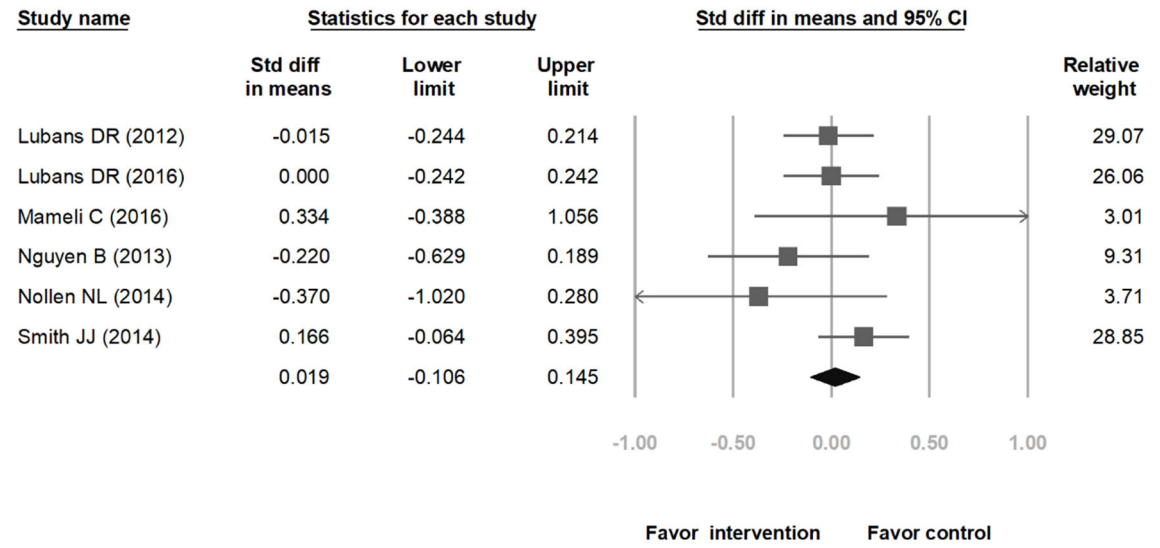


FIGURE 4 | The weight loss effect between the intervention and control groups of the non-ethnic Chinese participants.

studies consisted of follow-up periods of 8, 12, 18, and 24 months. Therefore, the weight loss effect of mobile health technology intervention on ethnic Chinese participants was only for a short term. Future studies on ethnic Chinese participants with longer follow-up periods are necessary. By using follow-up periods with the same duration, researchers can attain a greater understanding of the different effects of mobile health technology intervention on different ethnicity subgroups.

Based on the study results, we provide suggestions for future research. First, the meta-analysis of this study used mean BMI to measure weight loss results. Future studies may include other obesity measurement indices, such as BMI changes, zBMI, BMI%, body fat, and waist-hip ratio. Next, the meta-analysis only included three studies involving ethnic Chinese participants. Future studies should include more studies on obesity in ethnic Chinese children. Finally, future researchers may conduct long-term follow-up on ethnic Chinese participants to fulfill the current research gap of longitudinal research.

CONCLUSIONS

Mobile health technology applications have been widely used in preventing childhood obesity. However, the results were not as expected. The research results indicate that by using ethnicity as a moderating variable and under the effect of cultural and psychological factors, the use of mobile health technology intervention may reduce obesity in ethnic Chinese children. However, the weight loss effect of mobile health technology intervention in other ethnicities remains uncertain. Therefore, ethnicity culture must be used as a key consideration in future studies using mobile health technology interventions to reduce childhood obesity.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

R-HW, H-HW, and F-HC: conceptualization, methodology, and validation. J-MY: data curation, formal analysis, and writing original draft. J-MY and K-HC: investigation. R-HW: project administration, resources, and supervision. H-HW and F-HC: resources. K-HC: software. F-ST: visualization, writing-review, and editing.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.708321/full#supplementary-material

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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

Embase

#	Search syntax
1	(((childhood OR pediatric OR child* OR pupil OR adolescent OR teenage* OR juvenile OR kid) NEAR/4 (obesity OR overweight OR adiposity OR "weight management" OR "weight control" OR "weight loss" OR weight-loss)) OR ((obese OR overweight) AND (child* OR kid OR pupil OR adolescent))):ti,ab,kw,de
2	"childhood obesity"/exp
3	((smartwatch OR wristband OR mHealth OR "mobile health" OR "activity tracker" OR "fitness tracker") OR ((mobile OR electronic OR digital OR cloud OR wearable OR smart OR health OR fitness OR wrist-worn OR biofeedback OR wireless OR internet) NEAR/4 (tracker OR sensor OR application OR app OR device OR technolog* OR watch OR product OR wearable))):ti,ab,kw,de
4	"activity tracker"/exp OR "mobile health application"/exp OR "self-monitoring"/exp
5	(BMI OR "body mass index"):ti,ab,kw,de
6	"body mass"/exp
7	(#1 OR #2) AND (#3 OR #4) AND (#5 OR #6) AND [embase]/lim
8	#7 AND ("crossover procedure":de OR "double-blind procedure":de OR "randomized controlled trial":de OR "single-blind procedure":de OR (random* OR factorial* OR crossover* OR cross NEXT/1 over* OR placebo* OR doubl* NEAR/1 blind* OR singl* NEAR/1 blind* OR assign* OR allocat* OR volunteer*):de,ab,ti)

frontiers in Public Health

ORIGINAL RESEARCH
published: 03 September 2021
doi: 10.3389/fpubh.2021.715768

A Structured Pathway Toward Disruption: A Novel HealthTec Innovation Design Curriculum With Entrepreneurship in Mind

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OPEN ACCESS

Edited by:
Mihajlo (Michael) Jakovljevic, Hosei University, Japan

Reviewed by:
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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *27 May 2021*
Accepted: *11 August 2021*
Published: *03 September 2021*

Citation:
Fritzsche H, Barbazzeni B, Mahmeen M, Haider S and Friebe M (2021) A Structured Pathway Toward Disruption: A Novel HealthTec Innovation Design Curriculum With Entrepreneurship in Mind. Front. Public Health 9:715768. doi: 10.3389/fpubh.2021.715768

The typical curriculum of training and educating future clinicians, biomedical engineers, health IT, and artificial intelligence experts lacks needed twenty first-century skills like problem-solving, stakeholder empathy, curiosity stimulation, entrepreneurship, and health economics, which are essential generators and are pre-requirements for creating intentional disruptive innovations. Moreover, the translation from research to a valuable and affordable product/process innovation is not formalized by the current teachings that focus on short-term rather than long-term developments, leading to inaccurate and incremental forecasting on the future of healthcare and longevity. The Stanford Biodesign approach of unmet clinical need detection would be an excellent starting methodology for health-related innovation work, although unfortunately not widely taught yet. We have developed a novel lecture titled HealthTec Innovation Design (HTID) offered in an interdisciplinary setup to medical students and biomedical engineers. It teaches a future-oriented view and the application and effects of exponential trends. We implemented a novel approach using the Purpose Launchpad meta-methodology combined with other innovation generation tools to define, experiment, and validate existing project ideas. As part of the process of defining the novel curriculum, we used experimentation methods, like a global science fiction event to create a comic book with Future Health stories and an Innovation Think Tank Certification Program of a large medical technology company that is focused on identifying future health opportunities. We conducted before and after surveys and concluded that the proposed initiatives were impactful in developing an innovative design thinking approach. Participants' awareness and enthusiasm were raised, including their willingness to implement taught skills, values, and methods in their working projects. We conclude that a new curriculum based on HTID is essential and needed to move the needle of healthcare activities from treating sickness to maintaining health.

Keywords: biodesign, design thinking, health democratization, bioengineering education, disruptive technologies, exponential medicine, future of health, twenty-first century skills

INTRODUCTION

Innovation has been defined as the result of implementing new or improved products/services/processes to enhance a specific value (1). In healthcare, innovation represents a novel technology, service, or care process that aims to bring benefits compared with previous methods due to its usability and desirability (2). Although an urgent need to facilitate the healthcare system while moving the value from diseases and treatments to patient care and prevention, innovation results faster and wiser in other sectors than in healthcare.

Nowadays, several issues should be addressed to face challenges when implementing innovation in the health domain: needs for funding, use of advanced technologies, a patient-centric approach, the possible need and adoption of a new health business model, payments processing and invoicing, cyber- and data security, regulatory changes and approvals, increasing costs of healthcare delivery, investment in IT procedures and many others (3). Moreover, the focus on short-term (3–5 years) rather than long-term (>10 years) developments has solely the effect of generating inaccurate forecasting on the future of healthcare while preventing innovation from being disruptive (4).

How can we imagine healthcare in 10 years? What will be the effects of available tools and devices for prevention and prediction on diagnosing and treating diseases and on a healthy longevity? How do we deal with inequalities in healthcare delivery, access and increasing costs? Is the current education geared toward the anticipated changes? Questions need answers, and the proper problem identification leads to innovative, applicable solutions.

The current way of training and educating future clinicians, biomedical engineers, health IT, and artificial intelligence (AI) experts in education silos does not lead to disruptions but rather to incremental innovations (5–10). The necessity for innovative and adaptive approaches to improve outcomes brought us to think about a health innovation related adoption of the Design Thinking Approach; a novel way of problem-solving that aims to find the best fit-solution between the customer profile and a new product/service/process, quickly prototyped, and iteratively refined (11).

When compared to traditional problem-solving methods, design thinking brings sustainable and applicable solutions, facilitating improvements for patients, care facilities and communities, while improving management and collaborations toward public health procedures. Based on the outcomes introduced by this approach a closer look at the traditional educational curricula in and around health-related programs (engineering, natural science, clinical science), currently lacking twenty first-century skills (e.g., problem-solving, stakeholder empathy, curiosity stimulation, entrepreneurship, and health economics) is needed. Abookire et al. integrated Design Thinking to develop a workshop through the collaboration between the Health Design Lab and Colleges of Medicine and Population Health at Thomas Jefferson University to enrich traditional public health education curricula (11). The workshop aimed to train public health students to more efficiently and effectively deal with complex problems as future healthcare professionals and providers. Students were engaged to investigate public health problems by applying viable and feasible solutions, demonstrating the valuable role of Design Thinking as an innovative and empathy-driven approach in improving the health of individuals and the wellness of the entire community.

Results from the survey evaluation indicated that the familiarity with design thinking approach procedures increased enormously through the workshop. The students started to realize their abilities to implement meaningfully key concepts of the taught approach. Moreover, students demonstrated a positive attitude toward the event, considering it relevant and applicable in their current academic path and professional career. Participants were also given 10 min to generate low-fidelity prototypes. Ideas included the generation of devices to assist with schedule management and mobile application interfaces to ease physical movements and dietary changes.

On a similar perspective, a Lean Design Thinking approach has been suggested (12), which is an innovative model intended to merge the design thinking and lean startup strategies to help entrepreneurs and intrapreneurs by improving their current projects. The lean design thinking approach can be considered a source of inspiration toward innovation, adopting relevant tools and methods of both strategies, managing and generating business innovation with a customer-centered design. With increased attention toward social and environmental determinants of health (13–15) the study of entrepreneurial-driven public health innovation emerged as one of the ultimate approaches to generate innovative interventions, products, and services by addressing public health issues (14, 16).

Becker et al. (17) investigated the perceptions of graduate public health students regarding Public Health Entrepreneurship (PHE) (17); the application of entrepreneurial skills to accomplish public health missions (18), and their training needs for becoming future health professionals (19, 20). As the first research exploring perspectives of PHE in the academic setting, results from the study demonstrated positive outcomes. PHE was offered to be introduced in the current curriculum where courses incorporated the Council on Public Health Education (CEPH) competencies, actively involving students. Public health trainees were stimulated to apply wealth knowledge into action by combining the existing public health training methods with new social innovation and entrepreneurship (16, 21). Several advantages were highlighted when implementing PHE. Such as the correct identification of evidence-based solutions accompanied with the active ideation and application of prototypes to ameliorate health (22) and the possibility to engage stakeholders involved in public health even beyond sectors and institutions traditionally associated with health. This study confirmed that PHE could be the new way to increase resources by facing twenty first-century challenges in public health across several disciplines or sectors aligned with CEPH competencies. Moreover, the need for specific educational programs in life science technology innovation was previously anticipated by Yock et al. (23) and (9).

Design thinking and entrepreneurship education are considered major drivers behind and to create successful innovation. The Biodesign Program at Stanford University

provides a map of needs-driven MedTech innovation processes (identification–invention–implementation). Focused on training and educating students with a specific curriculum that integrates design thinking and commercialization processes, paving the way toward translational medicine (TM). In this context, Foty et al. (24) proposed an innovative curriculum design aimed at teaching scientists and leaders in the field of TM. A new curriculum was created to analyze the business scientific and regulatory aspects of TM, explore the challenges encountered by health professionals, develop critical thinking and communication skills by introducing the topic to a wide range of learners. TM is a new field of study that focuses mostly on integrating an idea, advancing clinical testing, and the final development of new technologies or drugs. For this reason, a broad set of skills are required and included in the TM program. Besides core concepts (e.g., ethics, regulations, funding, policy, etc.), TM skills include effective communication, interdisciplinary, personal reflection, and interprofessional collaboration.

Although the abundance of ideas and research projects in implementing a design thinking approach raises innovation in a health curriculum, these methods are not widely taught. The present research will describe a series of educational activities to advance health tech innovation. We developed a novel lecture titled HealthTec Innovation Design (HTID) offered for medical students and biomedical engineers that teaches a futuristic view and application of exponential trends. Besides that, we implemented a novel approach using the Purpose Launchpad meta-methodology combined with other innovative tools to define and further exploit an actual project. Additionally, we initiated and promoted with global teams the Sci-Fi Hive Future of Health, a science fiction comic creation event looking 20 years into the future; and the Innovation Think Tank Certification Program (ITTCP, by Siemens Healthineers) focused on the future of health, based on medical technologies with a mid-term vision of a large Medical Technology company. Surveys were conducted to investigate the effectiveness of these events in stimulating and enhancing awareness, curiosity, and expertise toward applying advanced design thinking methods in the field of health tech innovation. The presented research study aims to create the base for establishing a new educational curriculum in Health Technology Innovation Design by integrating advanced methods to prepare future healthcare professionals leading to disruptive and exponential innovation (see **Figure 1**).

MATERIALS AND METHODS

For the understanding and process description in complex systems, such as the healthcare sector, the principles of top-down and bottom-up design were used:

Top-down, based on a global view, the abstract becomes more specific and increasingly subordinate; an overall problem is divided into sub-problems. For this, the Sci-Fi Hive event provided a vision of a great and whole future that is always more detailed and specially designed and formulated.

Bottom-up in that context means the opposite direction. One starts with a specific problem and concludes with the general and higher-level. The ITTCP was used for that point of view. It started with a clinical problem (i.e., coronary artery disease) and used potential pharmaceutical, technical, and organizational solutions for prevention, prediction, diagnosis, intervention, care, and aftercare.

Thus, two fundamentally different ways to understand, describe and present the complex future health issues were employed. Both are used to recognize the future—and with that, the effect on current—needs to adapt the education for bioengineering-, and medical- students, as well as for related fields (e.g., health economics, data sciences, computer sciences). Before and after the events, a qualitative survey was carried out to check relevant characteristics and provide information about them systemically.

Sci-Fi Hive

Eight teams of 11 participants were put together and assigned to different healthcare topics: the democratization of healthcare, future of emergency/care hospitals, future of homecare, future of increased health-span/longevity, future of health diagnostic, and future of overall health/wellness. After a short introduction to the future of healthcare and exponential innovations, the event was conducted into four main stages.

In the first stage, teams met individually to know each other and brainstorm the first ideas on the chosen healthcare topic.

In the second stage, teams started creating comic characters and developing the hero's journey story around the future vision.

In the third stage, before starting with the prototyping, teams described and scripted the hero's journey story into a comic book format.

Finally, the teams were ready to create and prototype the science fiction comic book cover and individual story panels in the last stage.

Each stage was followed by a feedback session in which teams had the opportunity to share their learning and insights. In total, the event lasted 8 h. The realized Sci-Fi Hive comic book is provided here in Friebe et al. (25).

We designed a pre-and post-event survey in English language using GOOGLE Forms consisting of 14 questions pre-, and 13 questions for the post-event survey as multiple choice, checkboxes, three or five-point Likert scale, short answer or yes/no modalities. Thirty-eight responses were collected from the pre-survey analysis, and 29 responses were collected from the post-survey analysis. Pre- and post-event survey questions and answers are listed in Appendix A in **Supplementary Material**.

Innovation Think Tank Certification Program

Innovation Think Tank Certification Program (ITTCP) is an "experiential learning training" based on the experience of successful implementation and management of Innovation Think Tank programs and innovation labs at Siemens Healthineers and several prestigious institutions worldwide. During the ITT program, interdisciplinary participants work in teams using the ITT approach to generate strategic content that helps Siemens Healthineers shape the technology and disease pathway strategy. Also, it helps the host organizations

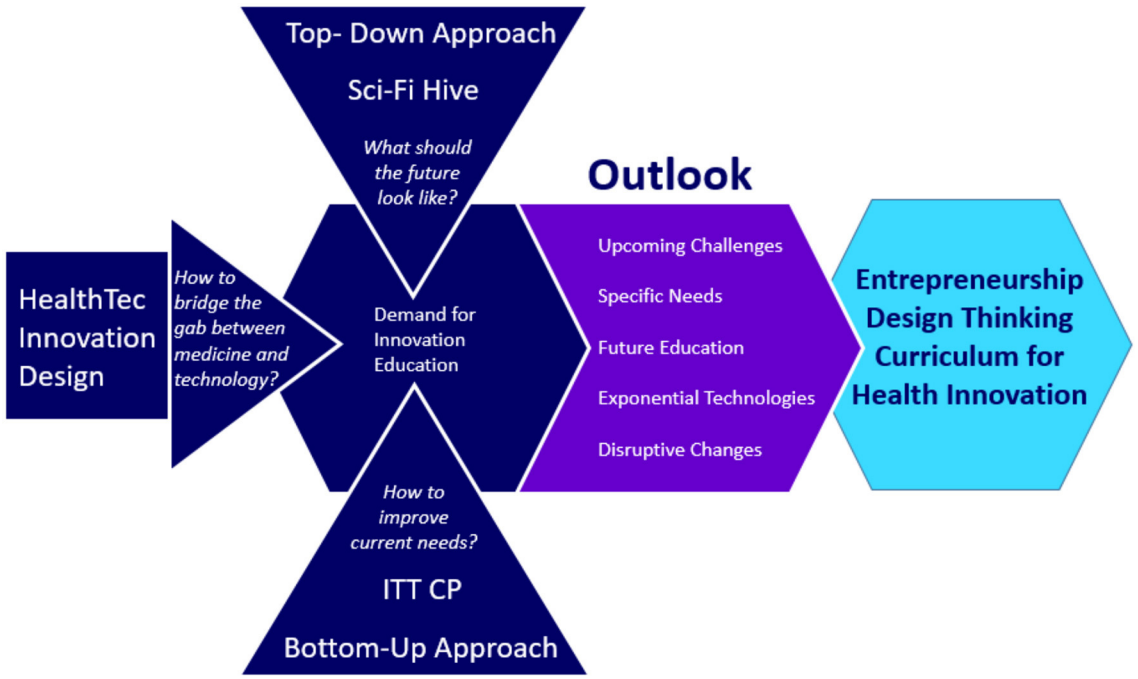


FIGURE 1 | Approaches for a new curriculum.

(customers) define concrete projects for further deep dives and research in the ITT lab. The interactive program is designed to develop creative pioneers capable of delivering innovative and customer-centric solutions to the world's most significant challenges in Healthcare in their field of profession.

For the data collection we designed a pre-and post-event survey in English language using GOOGLE Forms consisting of 14 questions pre-, and 11 questions for the post-event survey, again as multiple choice, checkboxes, five-point Likert scale, short answer or yes/no modalities. Forty responses were collected from the pre-survey analysis, and 28 responses were collected from the post-survey analysis. Pre and post-survey questions and answers are listed in Appendix B in **Supplementary Material**.

The survey answers from the Sci-Fi Hive and ITTCP were statistically analyzed based on the frequency distributions. The frequencies were computed based on the median distribution. In particular, the most frequent answers were transformed into their valid percentage.

HealthTec Innovation Design Lecture

At the Otto-von-Guericke-University (OVGU) in Magdeburg, Germany, we developed a semester-long lecture titled HealthTec Innovation Design (HTID) offered for medical students and biomedical engineers that teaches a futuristic view and application of exponential trends (23). The HTID, rated 5 ECTS, consists of 10 online lectures with 35 academic hours of teaching, and an additional 90 h of personal and team project assignments. Examples of personal assignments were identifying the personal Massive Transformative Purpose (MTP) and writing a manuscript in a research article format. Students were also asked to forecast and design the future of their current research/education project. Two interdisciplinary teams were formed during the lectures to exploit an actual project leading to developing health-tech innovative ideas. The teams were asked to develop the project using the Purpose Launchpad meta-methodology tool, the OpenExo tools, the classical Business Model Canvas and the Stanford Biodesign approach. In addition, teams were asked to write a short manuscript dedicated to their project proposal in a research article format. A final online examination with a multiple-choice test and a team project presentation concluded the semester earning a certificate of attendance of passed examination.

In further detail, during the lectures, a novel conceptual tool of identifying, validating, and implementation innovation using the Purpose Launchpad (26) was adapted to the healthcare field and combined with other innovative OpenExo tools (27), such as the OpenExo Canvas, to define and further exploit an actual project.

The Purpose Launchpad is a meta-methodology to evolve early-stages ideas into purpose-driven, exponential organizations generating massive impact. The Purpose Launchpad is defined as a mindset, a framework, and a methodology to develop an adequate innovative organization, business, product, or service. Moreover, this meta-methodology is articulated around eight principles (see **Figure 2**) purpose over a problem and problem over a solution, exploration over-optimization, talking to customers over market research, abundance over scarcity, sustainability over investment, mindset over processes and tools, validated learning over product building, qualitative over quantitative metrics.



FIGURE 2 | Purpose Launchpad meta-methodology. The eight principles around which the Purpose Launchpad meta-methodology is articulated are represented: purpose, people, customer, abundance, sustainability, strategies, product, and metrics.

The Purpose Launchpad can be applied as a set of principles or an iterative process that evolves continuously over the above-mentioned key area axes (purpose, people, customer, abundance, sustainability, strategies, product, and metrics). To enhance learning, the Purpose Launchpad includes evaluating progress through constant assessments over three evaluation levels: discovery, validation, and growth. Lastly, through innovation Sprints, the team makes real progress evolving the Purpose Launchpad Axes over daily/weekly meetings (see **Figure 3**).

RESULTS

Sci-Fi Hive

Most attendees were male entrepreneurs (35–50 years old) interested in exploring innovative healthcare (86.8%) and mainly new to similar events from the pre-survey analysis. When asked which innovative technology is already implemented (3–5 years' perspective) in participant's work/project, digital healthcare resulted in the most common response (68.4%). Differently, when speculating about the future implementation of technologies (>10 years' perspective), AI (65.8%), VR/AR (57.9%), brain-computer interfaces, or digital healthcare (55.3%) resulted in the most selected responses.

Prevention over treatment, patient empowerment, and personalized medicine was considered the most impactful values/perspectives to generate meaningful innovation in healthcare. Similarly, competencies (problem-solving, collaboration, creativity, communication) and character qualities (curiosity, persistence, adaptability, leadership, initiative, social awareness) were considered very important "innovation mindset" skills over literacy. Moreover, participants defined *innovation* as "the translation of an existing product/service/process into something more efficient/effective/competitive" (31.6%). They reported that the most relevant reason for failure in a startup/business/research/industry project dealing with healthcare innovation is designing a product without considering the customer profile/market test (36.8%). Lastly, several factors were identified as responsible for the prevention of disruptive innovation, such as regulatory approvals, government/political interests, traditional not transparent business model, and fear of changes, as well as, attendee agreed that the gap between scientific literacy and application is not widely exploited by the current university-based education (73.3%).

Moreover, most responders were male entrepreneurs and medical doctors (>35 years old) from the post-survey. Participants reported that the Sci-Fi Hive highly matched their expectations, finding it very informative and insightful (92.6%). Several terms were collected when we asked to describe the most meaningful Sci-Fi Hive take-away in one word. The most common words were *collaboration, creativity, teamwork, insightful, engaging, enlightening, excited, fiction, comic, innovation, imagination, inspiring, relaxed, interaction, fun, big vision, discussion, diversity, interesting, members, think out the box, and great.*

Furthermore, participants declared to be willing to implement the learnings from Sci-Fi Hive into their work/life to improve a current research/business/education project (65.5%) and that the taught methods were likely to raise innovation in their current projects. We asked which growth mindset perspective Sci-Fi Hive has stimulated. Based on a growth mindset approach, participants mainly reported that they were more willing to "try new things" (69%), that "challenges help me to grow" (51.7%). Moreover, "optimistic thinking," "passion and purpose," and "long-term thinking" were the most relevant mindset/thinking strategies to raise innovation. In conclusion, participants reported that Sci-Fi Hive was very impactful in stimulating their awareness toward the challenges behind healthcare innovation and that twenty first-century skills in problem-solving, critical thinking, creativity, communication, and collaboration are fundamental to grow an innovative mindset.

Innovation Think Tank Program

From the pre-survey analysis, most attendees were female students (18–24 years old) interested in exploring innovative healthcare (65%) and mainly new to similar events. When asked which innovative technology is already implemented (3–5 years' perspective) in participant's work/project, digital healthcare resulted in the most common response (47.5%). Differently, when speculating about the future implementation of technologies (>10 years' perspective), AI (57.5%), digital healthcare (55%), and VR/AR (50%) resulted in the most selected responses. Moreover, when asked which factor comes into mind when thinking about healthcare, the top 3 answers were "medical devices and technologies" (77.5%), "healthcare management" (42.5%) and "diseases" (40%), and that "treatment over prevention" has been classified as the main problem in the current healthcare delivery (47.5%). Prevention over treatment, personalized medicine, digital health procedures, and patient-centric approach was considered very impactful values/perspectives to generate meaningful

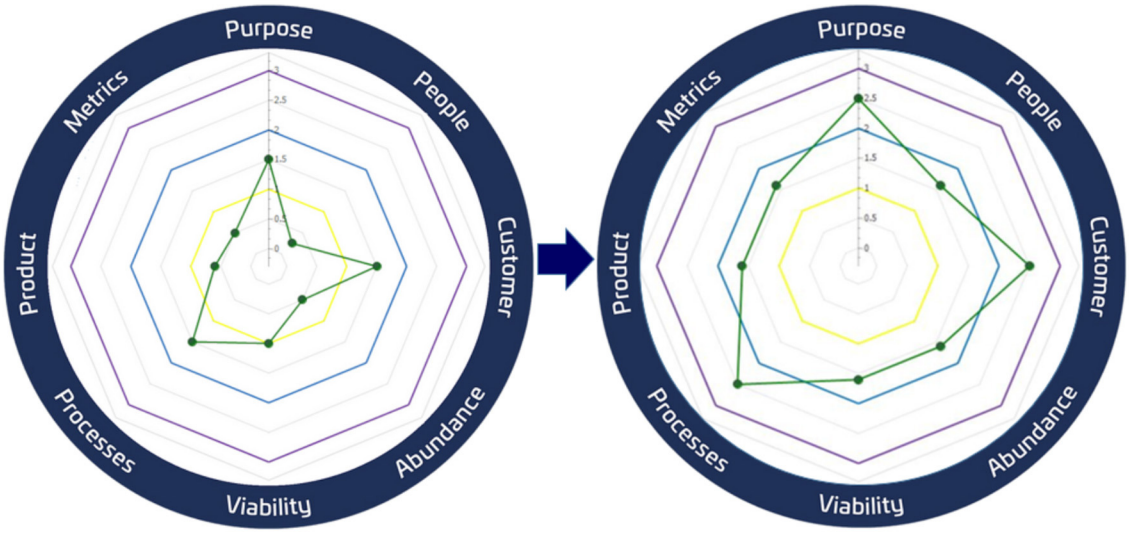


FIGURE 3 | Purpose Launchpad meta-methodology. To enhance learning, the Purpose Launchpad evaluates progress through constant assessments. In this way, the team makes real progress evolving the Purpose Launchpad eight principles over daily/weekly meetings.

innovation in healthcare. Participants defined innovation as "the translation of an existing product/service/process into something more efficient/effective/competitive" (35%). Lastly, several factors were identified as responsible for the prevention of disruptive innovation such as government/political interests, regulatory approval (e.g., CE, FDA), no transparent business model/markets, traditional/rigid education system, and a long time in the process of implementing new technologies, as well as, participants identified "training of twenty first-century skills" (45%) the main factor to close the gap between scientific literacy and feasible application to improve healthcare. Moreover, most respondents were female students (25–34 years old) from the post-survey. Participants reported that the ITTCP matched their expectations, finding it very informative and insightful (89.3%). Several terms have been collected when asked to describe the most meaningful ITTCP take-away in one word. The most common words were holistic view, mandate, teamwork, vision, interdisciplinary, informative, problem identification, methodology, insightful, enlighten, inclusivity and structure. Furthermore, participants declared to be willing to implement the learnings from ITTCP into their work/life to improve a current research/business/education project (60.7%). "Customer-centric thinking," "rapid experimentation," and "passion and purpose" were the three most crucial mindset/thinking strategies to raise innovation. In conclusion, participants reported that a "deep understanding of the problem to be solved" (46.4%) is the most challenging factor when implementing an innovation strategy/methodology to commercialize an invention. That "empathic and collaborative networks" (35.7%) is the most crucial factor needed to switch from the current healthcare methods to innovative healthcare strategy-approach and that "training of twenty first-century skills" the main factor to close the gap between scientific literacy and feasible application to improve healthcare (46.4%).

To summarize, the results obtained from Sci-Fi Hive and ITTCP can be compared, although some questions we provided were different between the two programs. In general, with a top-down approach, Sci-Fi Hive identified prevention over treatment, patient empowerment, and personalized medicine as the most impactful values/perspectives to generate innovation in healthcare, and that regulatory approvals, government/political interests, traditional not transparent business model, fear of changes were responsible factors to prevent disruptive innovation.

When forecasting the future implementation of technologies (>10 years' perspective) to generate innovation in healthcare, attendees reported that digital healthcare, AI, VR/AR and brain-computer interfaces would be the most preferred technologies. Moreover, twenty first-century skills were recognized as fundamental to grow an innovative mindset. Similarly, with a bottom-up approach, ITTCP identified the same factors as the most impactful values to raise innovation and those factors that prevent disruptive innovation and those technologies that preferably would be implemented in >10 years' perspective. Twenty first-century skills were again identified as necessary competencies needed to close the gap between scientific literacy and feasible application in healthcare. Attendees were satisfied and willing to implement the learnings from both events to improve their current research/educational project. A considerable difference between Sci-Fi Hive and ITTCP is related to the type of audience participating in these two programs, and so the way they would apply the learning into their current work project. From Sci-Fi Hive, most attendees were male entrepreneurs (35–50 years old), whereas from the

ITTCP attendees were mainly female students (18–24 years old), both categories interested in exploring innovative healthcare and mainly new to similar events. This factor results relevant when considering the educational/business meaning and goals behind these two events. Indeed, ITTCP starting with a bottom-up approach aims to identify clinical needs and search for possible solutions to generate a high-level frame of solutions. This approach would have a meaningful impact when educating and training future healthcare professionals because it teaches methods and strategies to solve unmet clinical needs. On the other side, Sci-Fi Hive starting with a top-down approach, aims to create a great and futuristic vision that can be successively divided into its parts, to make it happen. In this case, the approach can be relevant for healthcare entrepreneurs interested in translating an existing product/service/process into something more efficient/effective/competitive to solve unmet clinical needs through the best customer/market fit.

HealthTec Innovation Design Lecture

The semester-long lecture was completed successfully by all eight students from Medicine, Neuroscience, Biomedical Engineering, and Computer Science. The scope of personal assignment contents has been reached by students who have taken out meaningful insights. Divided into two equal interdisciplinary teams, students developed two projects to generate innovative solutions to satisfy unmet clinical needs. Teams demonstrated significant interest and involvement in their project, showing constant learnings during the semester. Moreover, the Purpose Launchpad meta-methodology, the Stanford Biodesign approach and the OpenExo tools were implemented successfully and appropriately. When asked students to present their team projects, presentations satisfied all the requirements, and the final examination was passed with good scores, meaning that students acquired the taught material with passion and purpose. Moreover, the HTID course with interdisciplinary students gave attendees the chance to know each other and exchange their expertise, learning and experiences, an optimal requirement in the perspective of healthcare innovation, and a revised educational curriculum. Finally, positive feedback from students suggested the continuation of this series of lectures with the vision of developing a novel curriculum in health-technology innovation design.

Currently, international differences in the education of the health science industry, the lack of emphasis on global healthcare care needs and interdisciplinary collaboration between healthcare providers, clinicians, research institutes and industries leads to the difficulty of identifying and satisfying clinical needs.

Thus, we aim to develop a novel educational curriculum based on the *I3-EME* as an educational concept (*Identify-Invent-Implement)* (28). The educational and teaching focus would be based on an interdisciplinary approach in which medical and engineering students would merge, working together on advanced clinical solutions based on the taught I3-EME Concept. The I3-EME aims to identify unmet clinical needs, invent feasible solutions and successfully implement them at adequate market needs. New technologies based on AI, AR, 3D, robotics, digital health, ethics, and future societal challenges, in line with medical technologies and services, will change the focus from inpatient to outpatient, prevention, reduction of costs, and democratization healthcare. Based on this educational content and the I3-EME concepts, students will have the opportunity to work and explore meaningful and valuable products/services to understand and solve global healthcare needs.

We proposed a study plan for this novel educational curriculum based on economy/business, medical/clinical/healthcare innovation and engineering study subjects, with corresponding credit points (CP). The medical and the engineering departments would interact with the hospital structures. The study plan will be structured into four semesters in which the subjects mentioned above will be covered (see **Table 1**).

DISCUSSION

How can we imagine healthcare in 10 years? What will be the effects of prevention and prediction on diseases and healthy longevity? How do we deal with inequalities and increasing costs? Is the current education geared toward the anticipated changes? We started with these questions to identify a proper solution.

When thinking about healthcare today, several obstacles should be addressed to overcome the current status and raise innovation. The main factors are the ever-increasing cost of healthcare provision, the disparity in quality care among countries and even inside countries from rural to urban, insufficient health insurance coverage, lack of empathy and communication between patient-providers, traditional and unilateral approaches, and fear of implementing new technologies.

These are just a few of the challenges that the healthcare system is facing nowadays. Although the urgent need to innovate and improve the healthcare system and services, the entire setup and management typically only leads to incremental rather than disruptive innovation. Incremental means that we observe improvements that do not significantly impact longevity but increase the cost significantly based on existing technologies and workflows.

One reason for this fact could be the current way of educating and training future clinicians, biomedical engineers, health IT, and AI experts in silos. The lack of transferability of scientific literacy to applicable solutions prevents the transformation of knowledge and ideas into innovative, feasible products to satisfy unmet clinical needs.

To close the gap between scientific literacy and application, we wanted to develop a novel lecture (dubbed HealthTec Innovation Design) for medical students and biomedical engineers that teaches a more futuristic view and includes applying exponential technologies in combination with teaching intentional disruption. We implemented a novel approach using the Purpose Launchpad meta-methodology and the Stanford Biodesign approach to define, experimentally validate and further

TABLE 1 | Proposed study plan suggestion for a novel master curriculum in Health Tech Innovation Design.

1. Semester	2. Semester	3. Semester	4 Semester
Marketing for Healthcare **5CP**	Value Based Technology and Innovation Management **5CP**	Entrepreneurial Finance and Venture Capital **5CP**	Master Thesis **20CP**
Market Research and Business Modeling **5CP**	Medical Innovation Needs 1 – Clinical Input (MI1) **5CP**	Discover UNMET CLINICAL NEEDS in a clinical Innovation Lab – think Entrepreneurial (UCN) **10CP**	
Innovation to Healthcare Democratization **5CP**	Individual Healthcare International – application of Value Proposition Canvas and Biodesign Principles (IHI) **5CP**		Health Economics and Reimbursement **5CP**
Healthcare Technology Innovation – future developments with high impact and need for change (HTI) **5CP**	Exponential Technologies and Designs for Extreme Affordability – Healthcare related (EXP) **5CP**	Medical Innovation Needs 2 – Screening, Diagnosis, Therapy, Prevention, Inpatient vs. Outpatient (MI2) **5CP**	Healthcare related Regulatory issues + Medical Product Risk Analysis (REG) **5CP**
20CP	20CP	20CP	30CP

The study plan articulates into four semesters covering economic/business with 50 CP (blue color), medical/clinical/healthcare innovation with 50 CP (purple) and the Innovation Lab in cooperation with the hospital with 10 CP (orange color).

exploit deep problem understanding to formulate an actual innovation project.

The learning from the global Sci-Fi Hive, a science fiction comic creation event, and the Innovation Think Tank Certification Program, both focused on the future of health but with different starting points, highlighted the need for a novel curriculum approach.

Through the implemented online surveys, we investigated the quality and efficiency of these educational programs and events. The survey results showed that most attendees were entrepreneurs, medical doctors, and students interested in exploring the topic of innovative healthcare. When speculating about the future implementation of technologies (>10 years' perspective), most responses were digital healthcare, AI, VR/AR, and brain-computer interfaces. Concepts like prevention over treatment, patient empowerment, and personalized medicine were considered the most impactful values/perspectives to generate meaningful innovation in healthcare. Factors like regulatory approvals (e.g., CE, FDA), government/political interests, unclear business model, and fear of changes were identified as responsible for preventing disruptive innovation. The lack of a customer profile/market test was the main reason for failure in a start-up/business/research/industry project dealing with healthcare innovation.

Moreover, innovation has been defined as the translation of an existing product/service/process into something more efficient/effective/competitive, and that twenty first-century competencies were considered very important "innovation mind-set" skills leading to innovation. More empathic and collaborative networks were identified with a deep understanding of the problem to be solved, respectively, as challenging and needed factors to generate an innovative healthcare strategy approach. Furthermore, attendees were satisfied regarding the overall programs/events outcome and willing to implement the taught methods to improve their current research/business/educational project. Attendees agreed that the gap between education and research application is still vast, estimating that training twenty first-century skills would be optimal to close this gap. A summary of the learned skills and continents from the different education programs leading to the novel curriculum development is reported in **Table 2**.

Based on our research results and the need of a revised education, our mission is to design a novel Master's Degree, called *Entrepreneurship Design Thinking Curriculum for Healthtech Innovation*, based on health technology innovation design, digital health methods, predictive and preventive medicine to reach our transformative goal in democratizing healthcare. Hence, we aim to establish novel curricula combining technical, economic, scientific and medical skills with twenty first-century skills to educate future health innovators and professionals. These curricula would comprehend programs taught in English, online teaching, on-site team projects and annual summer/winter schools. Through individual assignments, trimestral examinations, research team projects and tutoring support, students would be capable of reaching a novel degree in innovation generation aimed to generate the innovative mindset, attitude, and learning skills behind the feasible, valuable application of disruptive health technologies and finally moving the healthcare needle from sickness to health.

The master curriculum for Health Tec innovation design primarily aims at three interface areas for clinical innovation:

Healthcare economics (blue colored): Methods of health economic evaluation (benefit assessment, cost assessment, direct costs, indirect costs) play a significant role concerning healthcare democratization and require a deep understanding of economic processes and reimbursement for medical effectiveness and economic efficiency. Students are trained

TABLE 2 | Summary of the learned skills from the different educational programs—Sci-Fi Hive, ITTCP, HTID—needed to formulate the novel curriculum in Innovation Tech Design.

Sci-Fi Hive	ITT CP	HTID	Novel Curriculum in Healthtech Innovation Design
Twenty-First century skills	Twenty-First century skills	Twenty-First century skills	Twenty-First century skills
Interdisciplinary teams	Interdisciplinary teams	Interdisciplinary teams	Interdisciplinary teams
Top- Down Problem solving approach toward Innovation	Bottom- Up problem solving approach toward Innovation	From lectures (literacy) to the development of innovative projects (application)	Academic Transfer Strategies/Commercialization of Research Results (from literature to application)
The hero's journey story	The ITTCP methodology	Purpose Launchpad meta-methodology, OpenExo tools, the Stanford Biodesign approach	The HTID teaching methodology, the Stanford Biodesign approach, I3-EME-Concept
"Try new things," "challenges help me to grow," "passion and purpose," "optimistic thinking"	"Customer-centric thinking," "rapid experimentation," "passion and purpose"	"Growth mindset" approach	The HTID teaching methodology, the Stanford Biodesign approach, I3-EME-Concept
Fun, curiosity, creativity, interdisciplinary interaction	Structure, insight, methodology, interdisciplinary interaction	"Thinking out of the box," "learning from mistakes" approach, creativity, methodology, personalization, empathy, interdisciplinary interaction	International academic and industrial collaboration across countries to identify individual needs of the global healthcare challenges

in a financial analysis perspective and can decide on broad expertise in various economic backgrounds for research and innovation projects.

Innovation Methodologies (purple colored): with various agile innovation methods in product development, students can resolve any problem quickly and in a goal-oriented manner. In addition to the basics and the constant exchange in interdisciplinary groups, the students also learn to apply the methods they have learned in real projects.

Application-driven research (orange color): Students cooperate with the Innovation Lab and clinical departments to apply economic knowledge and innovation methodologies to detect unmet clinical needs, solve them with the newest approaches, and change the whole process.

CONCLUSION

Currently, university-based educational programs lack twenty first-century skills and innovative approaches, essential for identifying and implementing exponential technologies designed to cover unmet clinical needs. The nowadays trend is to look at innovation as just an incremental process, disregarding what is instead disruptive. To overcome these limits and stimulate innovative thinking, we developed a new lecture titled *HealthTec Innovation Design* for clinical and biomedical engineering students to teach a novel methodological approach to develop and implement disruptive health technologies.

Moreover, *Sci-Fi Hive*, a science fiction comic event, and *Innovation Think Tank Certification Program* raised interest and awareness toward a growth mindset behind disruptive innovation. From the survey results, we can conclude that our educational and initiative programs have impacted a growing interest in innovation, focusing on a distinctive design thinking approach. Participants raised awareness toward those values and perspectives needed to overturn the innovation process from incremental to disruptive, from literacy to valuable competencies and feasible applications. The programs developed the basement of a creative growth mindset, sharing tools and methods necessary when identifying and implementing a new product/process to detect and fulfill unmet clinical needs.

Moreover, participants reported being enthusiastic and willing to implement these new skill sets and methods to enhance their current research/business/educational project solicited by passion, purpose, and optimistic thinking.

Prevention, prediction, personalization, empathy and democratization; with different skills and innovative setups, we can design the future of health toward exponential medicine. Based on our results, we are convinced that developing a new curriculum based on HTID and educational programs/events such as Sci-Fi Hive and ITTCP would be essential. Hence, our vision is to raise the awareness needed to upgrade the global way of training and educating healthcare professionals enhancing the future of healthcare.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

BB and HF carried out the experiment, wrote the manuscript with support from MF, and designed the surveys. MM and SH supported us with respect to Siemens Healthineers Innovation Think Tank Certification Program. MF conceived the original idea and supervised the project. All authors contributed to the article and approved the submitted version.

FUNDING

This research was funded by the Ministry of Economy, Science and Digitization of the federal state of Saxony—Anhalt by EFRE funding in the context of the ego—INKUBATOR program (ZS/2019/04/98209/IK 27/2019) and by the European Structural and Investmen Funds (ESF, 2014-2020) under the program "Sachsen-Anhalt WISSENSCHAFT Internationalisierung" project numbert (ZS/2016/08/80645).

ACKNOWLEDGMENTS

The authors would like to thank all partners at the Sci-Fi Hive–the Future of Healthcare Event and at the Siemens Healthineers–Innovation Think Tank Certification Program. Furthermore, the authors would like to thank Francisco Palao for providing the Purpose Launchpad.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.715768/full#supplementary-material

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Conflict of Interest: MM and SH are employed by Siemens Healthineers, Erlangen, Germany.

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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frontiers in Public Health

ORIGINAL RESEARCH
published: 15 October 2021
doi: 10.3389/fpubh.2021.761031

Establishment of an Internet-Based Epidemiological Survey Data Collection Customized System Model

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Epidemiology occupies a very important position in preventive medicine. Its essence is to summarize the etiology and epidemic laws by studying the distribution and possible effects of diseases, so as to promote the formation of scientific epidemic prevention measures. The purpose of this article is to help relevant personnel complete the collection, induction, and analysis of epidemiological survey data by establishing a data collection system model to improve work efficiency. This article focuses on the new coronavirus pneumonia (COVID-19), investigates the development status of epidemiological survey data collection, and analyzes the problems in the current business process, and on this basis, develops a dedicated epidemiological survey System model for data collection. From the experimental data, the optimized correction evaluation index has been increased from 8.384 to 9.067. It can be seen that the combination of data mining algorithms and backpropagation algorithms can better improve the system's ability to process information. Professional information disclosure platforms can have a good positive impression on the prevention and treatment of epidemics. The Internet-based epidemiological survey customized system model established in this article is to integrate various epidemiological data so that people can correctly understand the spread of epidemics and promote the development of preventive medicine.

Keywords: internet age, epidemiological study, data collection, system model, collection customized system model

OPEN ACCESS

Edited by:
Fu-Sheng Tsai,
Cheng Shiu University, Taiwan

Reviewed by:
Chunlei Zhu,
China Pharmaceutical University, China
Mingzhong Liu,
Hefei University of Technology, China

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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *19 August 2021*
Accepted: *23 September 2021*
Published: *15 October 2021*

Citation:
Wang X (2021) Establishment of an Internet-Based Epidemiological Survey Data Collection Customized System Model. Front. Public Health 9:761031. doi: 10.3389/fpubh.2021.761031

INTRODUCTION

For a long time, epidemics have affected people's health and property safety, and they are extremely destructive and harmful. In recent years, various epidemics have broken out globally, such as measles, malaria, tuberculosis and so on. In addition, emerging epidemic problems are also increasing year by year, such as the new coronavirus pneumonia (COVID-19) that has gradually swept the world from the end of 2019. How to contain the outbreak of epidemics and alleviate the spread of diseases has become an urgent problem that must be faced by today's society. Considering the particularity of the epidemiological pathology, large-scale experiments cannot be carried out. Therefore, we can only simulate the spread of the disease through theory, predict the spread of the disease, and formulate reasonable prevention and control measures. In order to achieve this goal, it is very necessary to establish a special epidemiological survey data collection system model.

Data research on epidemiology has a history of many years abroad. Staa used a large drug epidemiological database to study oral corticosteroids and the risk of fractures. In order to assess the sensitivity of the relationship between oral corticosteroid use and fracture risk, he and his team collected a large number of patient data from the general medical research database as a strong basis for the study. Compared with a comprehensive general medicine database, if data is obtained from a specialized epidemiological drug database, the conviction of experimental results can be further enhanced (1). Gaudart studied the performance comparison between multilayer perceptron and linear regression in epidemiological data processing. The development of computer and Internet technology provides more powerful technical support for epidemiological data research, and neural networks are increasingly used as statistical models. Taking into account deviations such as normality, isomorphism, and error independence, Gaudart designed five designs and conducted a data simulation for each design. Judging from the experimental data, the prediction results have good stability, but more sample data are needed as evidence (2).

In recent years, domestic research on epidemiological survey data in the Internet age has also achieved fruitful results. Lin C F conducted research on the epidemiology of dyslipidemia in Asia-Pacific countries. In order to compare the epidemiology of dyslipidemia in the elderly and the general population in the Asia-Pacific region, he and his team collected differences in the prevalence of dyslipidemia in the elderly in China, Japan, South Korea, Malaysia and other countries. From the experimental data, the prevalence of high total cholesterol (TC) and high-low-density lipoprotein cholesterol (LDL-C) in most countries is higher than that of the general population. As the research objects involve various countries in the Asia-Pacific region, there are many difficulties in collecting epidemiological data. If a comprehensive data system model can be established based on the Internet, it will undoubtedly be of great help to improve research efficiency (3).

Based on the Internet and computer technology, this paper conducts in-depth research on the establishment of a customized system model for epidemiological survey data collection. The research is mainly carried out from the following aspects: First, this article introduces the related technologies and methods involved in the establishment of the system model, including Internet-based data collection systems, epidemiological data models, data mining algorithms, and anti-corruption systems. To the propagation algorithm. Secondly, after analyzing the problems and deficiencies in the original survey business, this article combines Internet technology with its key business processes, and uses the Architecture Modeling Method (IDEF) to complete the establishment of the epidemiological survey data customization system model. Finally, this article gives a detailed description of the collection and analysis of system data and the impact of the COVID-19 epidemic on global information management.

INTERNET-BASED EPIDEMIOLOGICAL SURVEY DATA COLLECTION SYSTEM TECHNOLOGY

Internet-Based Data Acquisition System

To use a computer to process and display information in the real world, you must first connect the computer with the real world. This needs to convert various signals in the real world into signals that can be identified and stored by the computer. This process is data acquisition (4, 5). Data acquisition technology is a comprehensive technology based on front-end analog signal processing, analog signal digitization, digital signal processing and computer control technology and other high-tech, which has been widely used in many fields (6). The development of digital technology promotes the progress of these fields to a certain extent. On the other hand, it puts forward higher requirements for data acquisition system. A large data acquisition system consists of the following parts: data measurement, data acquisition, data transmission, data storage, data processing, analysis and display (7).

In today's networked era, the development and application of computer network communications represented by the Internet has achieved unprecedented breakthroughs and successes. Networked measurement, acquisition and control technologies are developing with the development of network technology (8). The advantages of networked and distributed data collection are reflected in the expansion of the collection range, enhanced processing capabilities, more convenient information retrieval, and the ability to adapt to the changing needs of occasions (9). With these excellent performances, networked measurement and control have become an inevitable trend in the development of data acquisition technology. The rapid development of sensor technology, computer technology and network technology and the resulting measurement requirements have become an inexhaustible driving force for the development of data acquisition technology, and proposed newer and higher requirements for measurement methods and measurable data acquisition technology. The type and scope should be continuously expanded and updated, the accuracy should be improved, the reliability should be enhanced, and be able to adapt to the needs of various experimental environments (10, 11).

Data Model Based on Epidemiology

A lot of information will be involved in the epidemiological survey data collection process. For this reason, the data collection method and the authenticity of the information should be scientifically analyzed in the process of its realization (12). At the same time, due to the rapid development of science and technology and a large number of applications in practice, many advanced data acquisition and analysis technologies have emerged. For medical and health organizations, in order to improve work efficiency and calmly respond to changes in real-time information, a deep understanding and skilled use of data mining (DM) models are particularly important (13, 14).

Since the outbreak of the novel coronavirus pneumonia (COVID-19), my country has adopted various measures to

combat the epidemic. Among them, the real-time and accurate release of information on the epidemic by local governments has played a great role in stabilizing people's sentiment and controlling the epidemic. The openness and transparency of my country has made China praised by the world (15). From a professional point of view, the survey data on epidemics can allow the government and professional institutions to have an accurate grasp of the real-time spread and spread of the disease, so as to better make the corresponding counterparts; from a social point of view, the official The given professional information data can also prevent the masses from falling into panic and increase the masses' sense of trust in the government (16).

Data Mining Algorithm

With the rapid development of database technology, database management system has been more and more widely used. People have accumulated more and more data, and there are many important information hidden behind the surge of data. People hope to analyze it at a higher level in order to make better use of these data (17). The current database system can efficiently implement data entry, query, statistics and other functions, but it cannot find the relationships and rules in the data, and cannot predict the future development trend based on the existing data (18). The lack of the means of mining the hidden knowledge behind the data has led to the phenomenon of "explosive data but poor knowledge". While a large amount of information brings convenience to people, it also brings a lot of problems: too much information, difficult to digest; difficult to distinguish between true and false; difficult to guarantee security; different forms, difficult to unified processing, etc. In the face of these challenges, data mining technology emerged and showed strong vitality (19, 20).

Association rules and cluster analysis are the two most common data mining methods. Apriori algorithm is a typical algorithm in association rules, and K-means algorithm is the core algorithm in cluster analysis (21, 22). This article will briefly describe the flow of the K-means algorithm. First, suppose the original data set is:

$$X = \{x1, x2, x3, \cdots, xn\} \tag{1}$$

After giving the number of classes K, randomly selectV points from the data set as the starting cluster, and use the Euclidean distance formula as the distance measurement standard to measure, and calculate the distance between each point and the K cluster centers., The new cluster center can be obtained:

$$Cj = \frac{1}{nj} \sum_{xm \in cj} xm, 1 \le j \le K \tag{2}$$

Set the objective function as:

$$J = \sum_{j=1}^{K} \sum_{xi \in Cj} \left| xi - cj \right|^2 \tag{3}$$

The flow of the K-means algorithm is shown in **Figure 1** below.

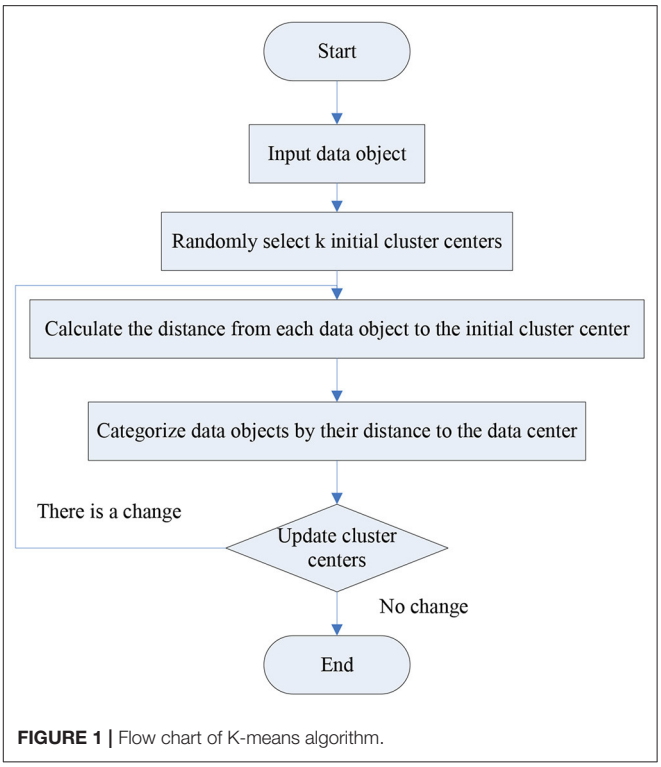


FIGURE 1 | Flow chart of K-means algorithm.

Backpropagation Algorithm

The multi-layer feedforward network learning algorithm is more complicated, because the hidden layer in the middle is not directly connected to the outside world, and its error cannot be directly calculated (23). In order to solve this problem, people found back propagation (BP) algorithm in the research process. Its main idea is to propagate the error of output layer layer layer by layer from back to front to calculate the error of hidden layer indirectly. In the back-propagation algorithm, in order to speed up the convergence speed, the gradient method can be used to modify the weight (24). Considering that the output function must be differentiable, the Sigmoid function can be used:

$$f(x) = \frac{1}{1 + \exp(-x)} \tag{4}$$

Given that the input vector is $X = (x1, x2, \cdots, xn)^T$, the hidden layer output vector is $Y = (y1, y2, \cdots, yh)^T$, the output layer vector $O = (o1, o2, \cdots, om)^T$, and the expected output vector is $d = (d1, d2, \cdots, dm)^T$, the input and output of the kth neuron in the output layer are:

$$netk = \sum_{j=1}^{h} wjkyj \qquad k = 1, 2, \cdots, m \tag{5}$$

$$ok = f(netk) \qquad k = 1, 2, \cdots, m \tag{6}$$

The input and output of the j th neuron in the hidden layer are:

$$netj = \sum_{i=1}^{n} vjkxi \qquad j = 1, 2, \cdots, h \tag{7}$$

$$yj = f(netj) \qquad j = 1, 2, \cdots, h \tag{8}$$

Generally speaking, the actual output of the network is not equal to the expected output, that is, there is an error E, and its definition satisfies:

$$E = \frac{1}{2}(d-o)^2 = \frac{1}{2}\sum_{k=1}^{m}(dk-ok)^2 \tag{9}$$

The principle of adjusting network weights is to continuously reduce the error, so the adjustment of the weights should be proportional to the negative gradient of the error, namely:

$$\Delta wjk = -\eta\frac{\partial E}{\partial wjk} = -\eta\frac{\partial E}{\partial netk} \bullet \frac{\partial netk}{\partial wjk} \qquad j = 1, 2, \cdots, h \tag{10}$$

$$\Delta vij = -\eta\frac{\partial E}{\partial vij} = -\eta\frac{\partial E}{\partial netj} \bullet \frac{\partial netj}{\partial vij} \qquad i = 1, 2, \cdots, h \tag{11}$$

At the same time, the error function can be further written as:

$$E = \frac{1}{2}(d-o)^2 = \frac{1}{2}\sum_{k=1}^{m}[dk - f(\sum_{j=1}^{h} wjkyj)]^2 \tag{12}$$

TTherefore, the calculation formula of the weight adjustment from the hidden layer to the output layer is:

$$\Delta Wjk = \eta(dk-ok)f'(netk)yj \tag{13}$$

The calculation formula for weight adjustment from the input layer to the hidden layer is:

$$\Delta Wij = \eta\sum_{k=1}^{m}\left[(dk-ok)f'(netk)wjk\right]f'(netj)xi \tag{14}$$

If the Sigmoid function is selected for the output of the hidden layer and the output layer, consider:

$$f'(x) = f(x)[1-f(x)] \tag{15}$$

The variants of formulas (13) and (14) are:

$$\Delta Wjk = \eta(dk-ok)ok(1-ok)yj \tag{16}$$

$$\Delta Wij = \eta\sum_{k=1}^{m}\left[(dk-ok)ok(1-ok)wjk\right]yj(1-yj)xi \tag{17}$$

In practical applications, training samples should be input when learning. Each time all training samples are input is called a training cycle. Learning should be performed cycle by cycle until the objective function is generally the error function reaches the minimum or less than a given value (25, 26).

EXPERIMENT ON THE CONSTRUCTION OF AN INTERNET-BASED EPIDEMIOLOGICAL DATA COLLECTION SYSTEM

Experimental Background

To realize the construction of an effective epidemiological survey data collection system model, the cooperation between multiple links is required, among which the most basic is the collection of information and data. In the past, most of the data collection methods were implemented by staff through on-site surveys or telephone surveys. In the context of the Internet, online questionnaire surveys have also become an important channel for epidemiological data collection. Because epidemics often have the characteristics of short cycles and fast timeliness, in terms of timeliness, network systems are obviously more efficient than manual investigations. With this in mind, the design of questionnaires and data entry have become a very critical part of building a data collection system. In this era of big data, how to select valuable information from massive amounts of data to provide an effective basis for scientific decision-making is an important research direction for network system platform management and development.

Experimental System Development

After analyzing the problems and deficiencies in the original survey business, this paper combines Internet technology with its key business processes, and uses the Architecture Modeling Method (IDEF) to complete the establishment of a customized system model for epidemiological survey data. IDEF is a commonly used structural analysis method. In the research process of this article, the main goal is to build a system that can effectively realize data input, control and mechanism. Input is the element transformed by the function in the system, the control will determine the execution of the function, and the mechanism represents the resources needed to perform the activity. **Figure 2** shows the epidemiological survey data system model.

It can be seen from **Figure 2** that when setting the system model, this article first considers the design of the survey plan and the testing plan. After completing the construction of the general plan structure in combination with the system goals, the formulation of the questionnaire, the collection of survey data and the data standard A definition is given. Finally, this article also formulated relevant management rules for system users. The system administrator has the authority to manage all members, while data entry personnel and monitoring and analysis personnel are responsible for ensuring the normal operation of the system.

System Model of Experimental Components

When designing the epidemiological data collection model, this article hopes to give the system professionalism and a certain versatility at the same time, so as to avoid restarting the system every time a new epidemic occurs, and adding unnecessary workload. Considering that the content of epidemiological

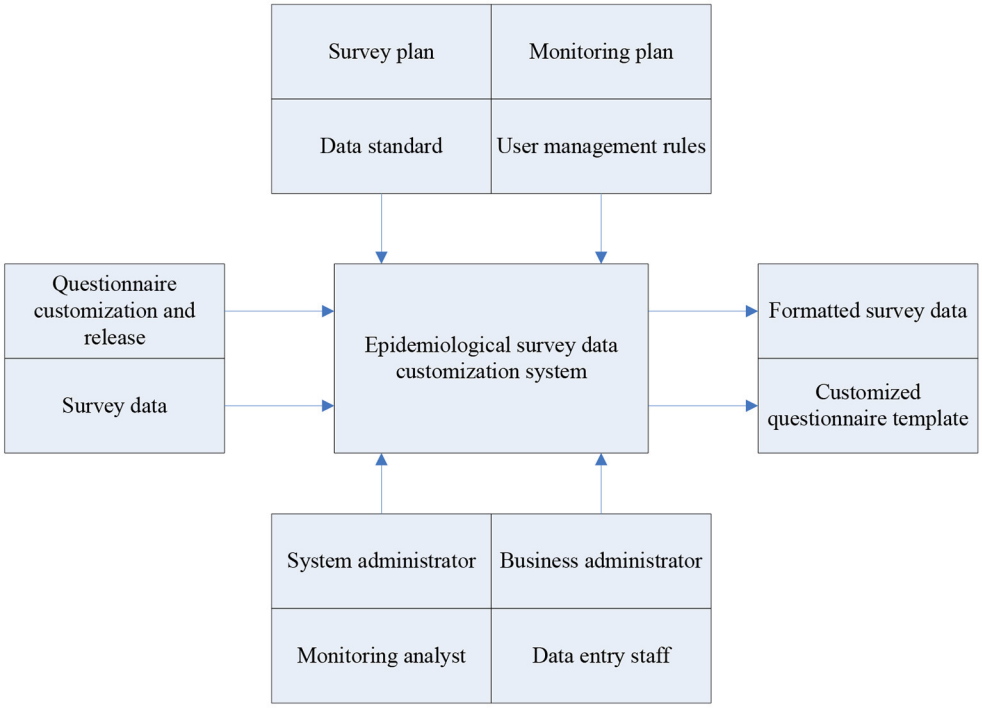


FIGURE 2 | Epidemiological survey data system model.

investigation involves many professional domain knowledge and diverse information, this article will realize the establishment of business model and data model based on components.

The essence of the component-based experimental model is to combine the analysis of business data to encapsulate the survey content and effectively achieve the effect of reuse. For example, when designing a questionnaire, in addition to a special database for new epidemics, many basic information components can be used repeatedly. For example, the user's name, gender, and ID number in the survey object information component; the time, location, and event level in the event component; the person who filled the form and the unit in the management information component, etc.

MODEL DESIGN OF AN INTERNET-BASED EPIDEMIOLOGICAL SURVEY DATA COLLECTION CUSTOM SYSTEM

Design of System Data Acquisition Based on Internet

In the process of epidemiological investigation, the most important link is the collection of data on the population infected by the epidemic every week, every day or even every hour. The more infectious and harmful viruses, the more necessary to update the system in time. The data allows officials and the masses to accurately grasp the changing status of communication. The absolute amount of intelligence of a data only reflects the scale of the current period. It is difficult to tell whether it is large or small in isolation. Only by comparing the data in different periods and observing its trajectory can the cause of the change be effectively analyzed and the correct judgment can be made.. Incremental analysis is mainly to calculate the growth rate. Through the year-on-year growth rate, the chain growth rate and the statistical graph, the system can better show the changes in the epidemic growth rate. **Table 1** and **Figure 3** show statistics on the number of newly confirmed cases of the epidemic in China from January to June 2020.

TABLE 1 | Statistics of newly diagnosed people in China.

	11	15	18	21	25	28
January	34	4	59	182	688	1,459
February	2,022	15,152	1,751	399	411	430
March	25	29	84	82	144	128
April	113	52	21	37	14	22
May	1	9	6	13	7	0
June	7	45	37	21	29	14

The display of collected data is the most important function in the epidemic disease customization system. It can be seen from **Table 1** and **Figure 3** that although the COVID-19 outbreak had cases as early as December 2019, the number of confirmed cases did not increase significantly until late January 2020. February became the peak of the outbreak, with the highest number of confirmed cases in a single day reaching 15,152. Compared with

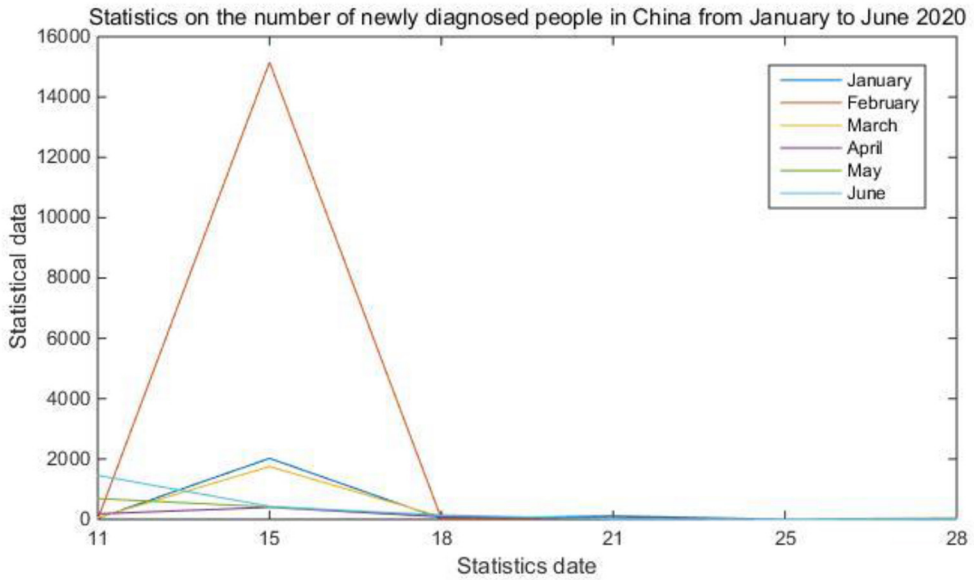


FIGURE 3 | Statistics of newly diagnosed people in China.

TABLE 2 | Trend of cumulative diagnoses in key epidemic countries.

	3.18	4.14	5.25	7.05	8.15	9.25
India	151	10,541	141,228	697,887	2,461,190	5,562,663
Brazil	291	23,955	363,211	1,603,055	3,224,876	4,558,040
Russia	147	21,102	353,427	686,777	912,823	1,111,157
America	6,552	587,752	1,689,727	2,983,155	5,415,666	7,046,216
Italy	31,506	159,516	229,858	241,611	252,235	299,506
England	2,626	94,823	260,916	314,992	315,600	401,127

the data indicators in the table, the statistical graph can clearly reflect the changes in the growth rate and speed more intuitively.

The proportional analysis method is the main method to analyze qualitative data. A single analysis of the absolute quantity of the frequency of a certain data item in qualitative data does not make much sense. Only by analyzing the proportion of each data item in the total and the proportional relationship between them can we get the results that people care about. The proportional analysis method is to first calculate the percentage of each option frequency of the indicator to the total frequency to obtain the current period, and then further use the incremental analysis method to study the changing law of the data in each period. In the epidemiological survey data collection system, in order to grasp the changes in the number of confirmed cases of the global epidemic and promote the development of information globalization, this article adds the data changes of the world epidemic to the system. **Table 2** and **Figure 4** show the cumulative confirmed trends in key epidemic countries.

From **Table 2** and **Figure 4**, we can clearly see the changes in the number of confirmed cases in several key epidemic countries such as the United States, India, and Brazil. As early as March, the World Health Organization defined the COVID-19 outbreak as a global pandemic. Most epidemics will only spread in local areas. If there is a pandemic on a global scale, relevant organizations and the masses need to pay more attention to it. Considering this kind of situation, this article carried out business reorganization by extracting the commonality of business process modeling when designing the system data collection. In this way, a data collection system with a universal scope can be better designed to collect and summarize epidemic data information on a global scale.

Data Analysis of Epidemiological System Based on Internet

The most important feature of a pandemic virus is that it can spread widely in a short period of time. Therefore, the epidemiological data system has a very important goal, which is to conduct disease transmission risk assessment by collecting data and information, and to give professional prevention suggestions.. During this COVID-19 epidemic, officials will report the changes in the number of infections in various provinces and cities every day, and some service systems will even provide the location of the patient's residence to increase the vigilance of nearby people.

In the design concept of this article, an excellent epidemiological data collection system can become a platform for communication between officials and the masses, allowing the masses to learn about the changes in the epidemic in real time. For these considerations, this article believes that data mining algorithms should be introduced into the data collection system, that is, to select valuable data from massive amounts of big data, and coordinate the data for different purposes, and present the summary results clearly and easily to the system user.

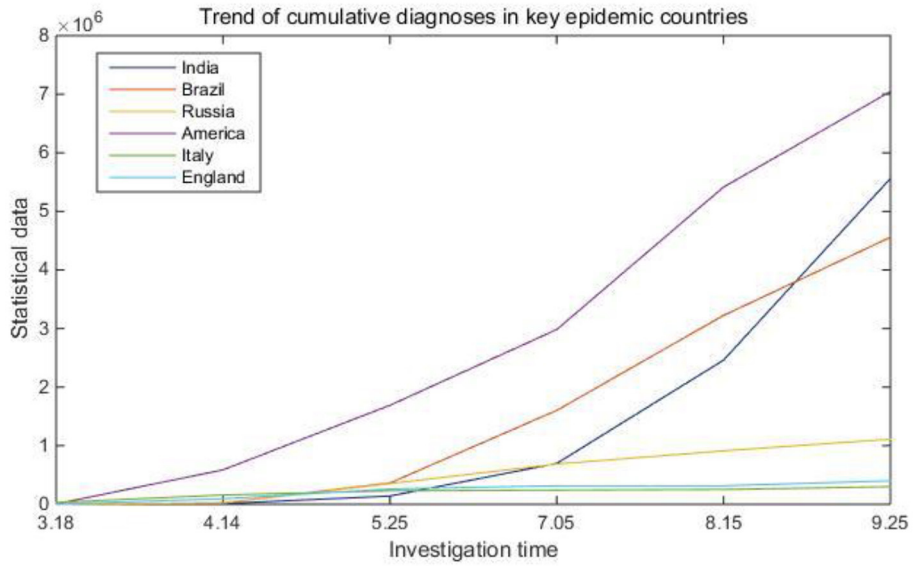


FIGURE 4 | Trend of cumulative diagnoses in key epidemic countries.

TABLE 3 | Cumulative trend of China's epidemic.

	1.11	2.5	2.25	3.10	4.2	5.12	6.14	7.30	9.08
Confirmed	41	31,211	78,630	80,924	82,802	84,458	84,778	88,122	90,582
Mortality	1	637	2,747	3,140	3,331	4,644	4,645	4,668	4,740
Cured	6	1,542	32,531	59,982	76,785	79,594	79,913	81,227	85,411

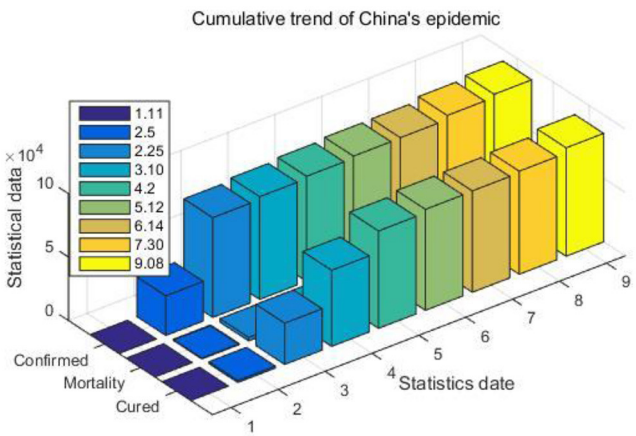


FIGURE 5 | Cumulative trend of China's epidemic.

TABLE 4 | Statistics of the severity of the epidemic in foreign countries.

	4.09	5.06	5.25	6.30	8.01	9.14
Spain	17,644	8,930	6,071	6,814	11,324	62,227
France	7,936	6,752	5,778	5,170	5,692	22,723
Belgium	3,935	6,565	6,782	6,019	6,697	12,109
America	13,476	40,086	40,708	52,496	86,940	94,957
England	5,280	21,778	30,905	33,439	27,993	35,183

Table 3 and **Figure 5** show the cumulative trend of the epidemic in China.

It is obvious from **Table 3** and **Figure 5** that from January to March, the number of confirmed cases of COVID-19 was in an explosive growth period in my country. During this period, the system will update the data accumulation situation in real time at a frequency of half an hour, and publish the latest epidemic information of various provinces and cities in the system news template.

Compared with some data changes with obvious regularities, the survey data of epidemics often have more uncertainties. When an acute respiratory infectious disease like COVID-19 appears in its early stages, no one would have expected that it will eventually develop into a global pandemic that infects tens of millions of people. However, as time goes by, it is possible to predict future trends from gradually stable data changes. To infer future trends, regression analysis methods are usually used. Regression analysis is a statistical method and technique that examines the quantitative changes between a number of independent variables x and dependent variables y. Regression

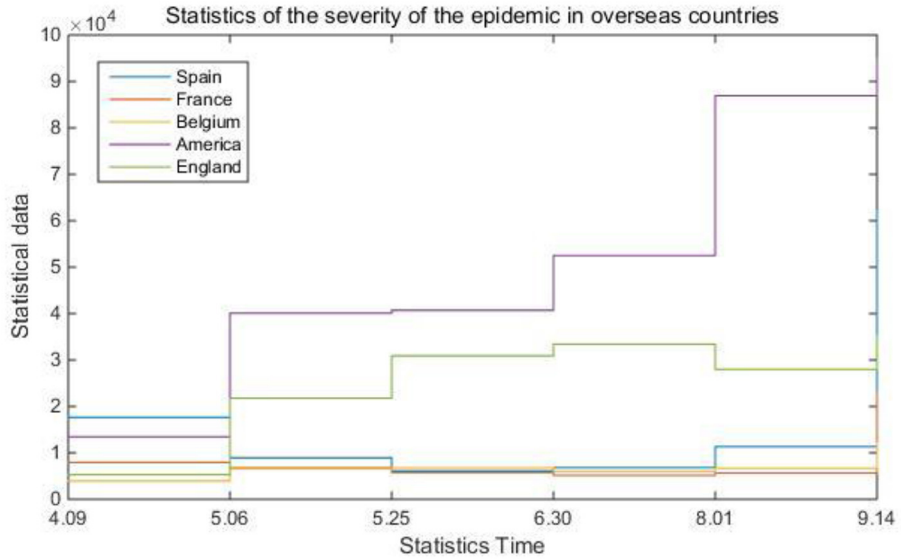


FIGURE 6 | Statistics of the severity of the epidemic in foreign countries.

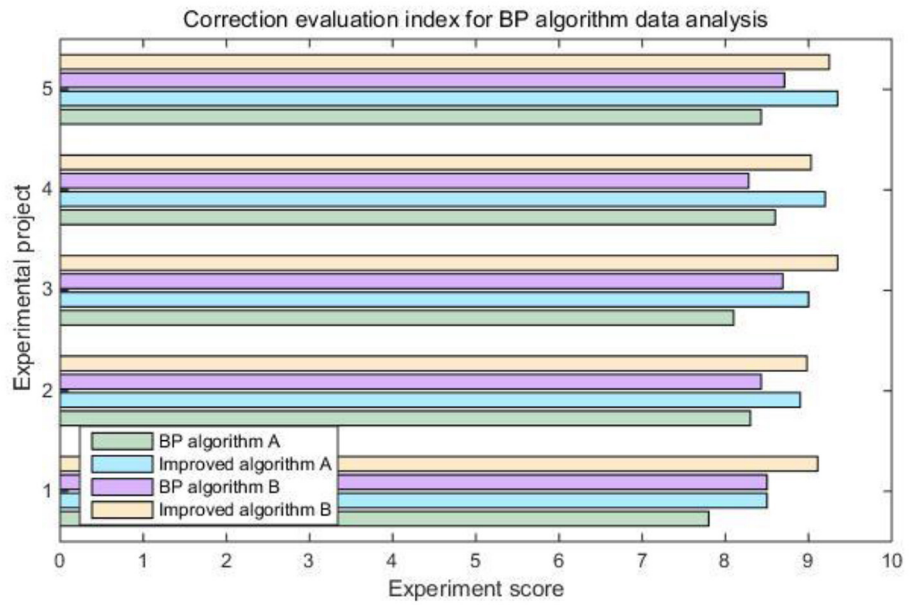


FIGURE 7 | Correction evaluation index for Bp algorithm data analysis.

analysis hopes to obtain a mathematical expression of the connection between the independent variable and the dependent variable, and estimate and predict the dependent variable through the known independent variable. The general steps of regression analysis are as follows: starting from the sample data, determine the mathematical relationship between the variables; estimate the regression model parameters; statistically test the relationship to find out the significant variables.

In real life, there are many uncertain factors that affect the spread of epidemics. In this case, computer technology is needed as assistance, such as eliminating useless information that interferes with prediction through data mining algorithms, and improving system information processing through backpropagation algorithms ability. **Table 4** and **Figure 6** are statistics on the severity of the epidemic situation in overseas countries.

Combined with the system's built-in computer intelligent algorithm, this article gives the concept of the epidemic severity index. That is to say, comprehensively refer to multiple data such as the global population, the global urban construction area, the number of existing confirmed populations, and the existing confirmed population density to judge the current severity of the epidemic in different countries. It can be seen from **Table 4** and **Figure 6** that the severity of the epidemic situation in most countries has fluctuated to varying degrees. In contrast, the severity of the epidemic index in the United States has basically remained rising. **Figure 7** shows the correction evaluation index of the data analysis in the simulation experiment of the backpropagation algorithm after the weight is corrected by the gradient method.

According to **Figure 7**, it is not difficult to see that the back propagation algorithm after modifying the weight by gradient method can play a better information processing effect in the epidemiological survey data collection system. The optimized correction evaluation index has been increased from 8.384 to 9.067. When combined with data mining algorithms, it can effectively improve the efficiency of data processing.

TABLE 5 | Comparison of data on cure rates of epidemics in various countries.

	2.25	3.22	4.10	5.05	6.12	7.18	8.31
Italy	0.35%	11.33%	20.05%	39.11%	72.56%	80.54%	77.75%
China	41.37%	90.16%	93.48%	93.84%	94.37%	93.71%	94.09%
Russia	100%	5.23%	7.69%	12.79%	52.57%	70.93%	81.52%
America	1.89%	0.38%	5.82%	15.12%	39.77%	46.16%	55.49%
France	33.33%	12.17%	18.13%	31.04%	37.54%	37.5%	28.36%
India	100%	8.13%	9.12%	28.69%	49.21%	62.61%	76.63%

TInfluence of Internet-Based Epidemiological System on Information Management

In practical problems, the factors that affect the dependent variable are very diverse. This regression of one dependent variable with multiple independent variables is called multiple regression. In real life, the impact of the COVID-19 epidemic on all parts of the world is huge. It not only threatens human life, health and safety, but also affects the development of the global economy. In addition, the epidemic has also had a considerable impact on the original global information management system and digital business in life, making people aware of the importance of information and data management in the Internet era. **Table 5** and **Figure 8** compare the data on the cure rate of epidemics in various countries.

It can be seen from **Table 5** and **Figure 8** that during the epidemic, China's cure rate has a very obvious advantage compared with other countries. This is naturally due to the country's effective epidemic prevention measures and treatment methods, but on the other hand, Official and reasonable information management methods have also played a good role in it. During the epidemic, the state and government update official survey data in real time through open channels, and the public can learn about the severity of the local epidemic and various epidemic prevention policies through the Internet. In this information age, if there is no official channel to disclose professional data in a timely manner, the masses are easily affected by the wrong information spread by some criminals. From this perspective, it is enough to prove how important a professional information disclosure platform is. The Internet-based epidemiological survey customized system model established in this article is to integrate various epidemiological data so that people can correctly understand

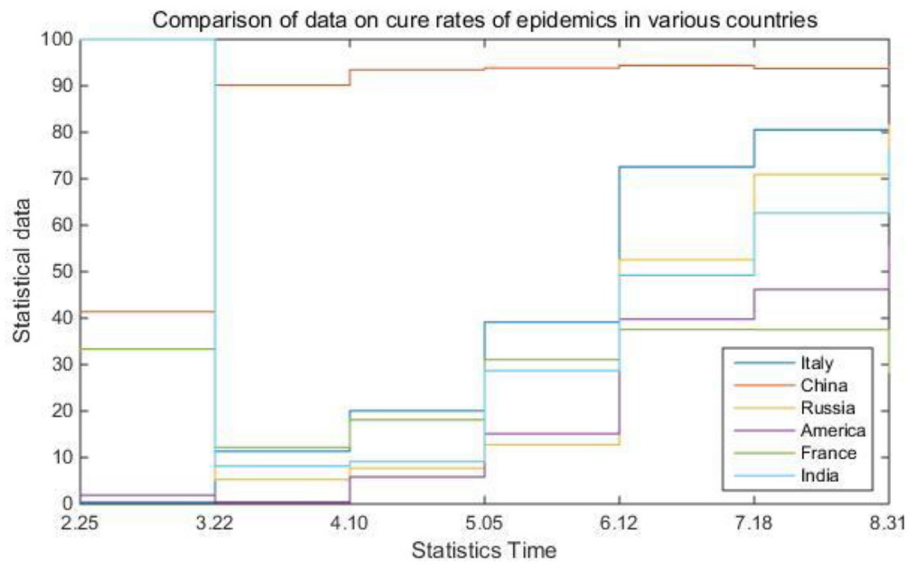


FIGURE 8 | Comparison of data on cure rates of epidemics in various countries.

the spread of epidemics and promote the development of preventive medicine.

CONCLUSIONS

Traditional epidemiological surveys mostly fill out paper questionnaires in person or over the phone. However, with the development of the Internet, this type of survey and data methods have obviously no longer adapted to the pace of the times. The survey data involved in epidemiology not only has many types, but also has higher requirements for real-time performance. Therefore, this article believes that the establishment of a special epidemiological survey data system through the Internet can better improve work efficiency and achieve scientific realization Information management. This article uses COVID-19 as a typical case, analyzes the possible problems and obstacles in the data collection process, and develops a customized epidemiological data collection system model with sufficient professionalism and practicability.

This study analyzed the business requirements of the epidemiological survey system, and designed a database table combining the attribute data of the survey unit and the spatial data. Based on the global COVID-19 epidemic survey data, this article analyzes the number of confirmed cases, severity index, cure rate and other indicators in several major epidemic countries from the perspectives of total indicators, incremental analysis methods, and proportional analysis methods, combined with tables in the system Data and statistical charts can clearly grasp the spread of epidemics. During this epidemic, my country's excellent information management strategy reflected to a certain extent the importance of data disclosure in the information age. Establishing an Internet-based customized epidemiological survey system model can not only integrate various epidemiological data, but more importantly, allow people to correctly understand the spread of epidemics and promote the development of preventive medicine.

In the research process, this article has achieved certain results. Nevertheless, due to various constraints, the research has certain limitations. In future research, this article believes that the experimental results can be further improved from the following perspectives: (1) Improve data mining algorithms and continuously improve the system's ability to analyze data in the era of big data; (2) Optimize the data management system The query function provides users with richer query services; (3) Improve system security protection capabilities to ensure the accuracy of data transmission.

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/s.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

FUNDING

This work was supported by the National Natural Science Foundation of China (Grant No. 61704138) and the Natural Science Foundation of Shaanxi Province (Grant No. 2020JQ-655).

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frontiers in Public Health

ORIGINAL RESEARCH
published: 24 November 2021
doi: 10.3389/fpubh.2021.772117

Citizen Characteristics and Their Participation in Food Safety Social Co-governance: Public Health Implications

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Objective: Given that positive psychological capital motivates citizens to actively participate in social affairs, this study aims to provide insight into food safety risk management in China by empirically determining which individual characteristics are associated with positive psychological capital for actively participating in social co-governance.

Methods: A questionnaire-based survey was undertaken between December 5 and 10, 2020. The study participants were residents of Wuxi in China over the age of 18 years. A validated and pretested questionnaires was used to elicit responses with the participants. Student's *t*-test and one-way analysis of variance were performed to determine which individual characteristics are significantly correlated with the psychological capital of citizens who participate in co-governance. *Post-hoc* multiple comparisons were performed for each individual characteristic with a significant correlation to determine which categories of these characteristics yielded the significant differences. Study data were analyzed using IBM SPSS Statistics 24.0.

Results: A total of 752 completed responses were received. Most respondents were females (52.39%), aged 26–45 (66.09%), married (70.48%), company employees (44.28%), and in good health (89.76%). Most had a household size of 3 (55.98%), a bachelor's degree (40.96%), a personal annual income of more than 100,000 yuan (26.46%), and no children aged under 18 (50.27%) or pregnant women (93.22%) in their households. Data analysis indicated that education, income, and health status significantly associate with the psychological capital of citizens to participate in co-governance. Citizens with high education, high income, and good health status have higher psychological capital to participate in co-governance.

Conclusion: The present study suggested citizens are likely to actively participate in food safety social co-governance only when they have at least one of the following three characteristics: (1) higher than average income in their city of residence; (2) a bachelor's degree or higher education; or (3) good health. Therefore, motivating citizens

OPEN ACCESS

Edited by:
Xiao-Bing Zhang,
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Reviewed by:
Li Yufeng,
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Amâncio António De Sousa Carvalho,
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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *07 September 2021*
Accepted: *21 October 2021*
Published: *24 November 2021*

Citation:
Chen X, Qin K and Wu L (2021) Citizen Characteristics and Their Participation in Food Safety Social Co-governance: Public Health Implications. Front. Public Health 9:772117. doi: 10.3389/fpubh.2021.772117

to participate in co-governance is a long-term process in China. The fundamental strategy is to increase the income of citizens, especially among low-income groups, promote education to improve the food safety literacy of the public, and improve sanitation and public health.

Keywords: citizen characteristics, psychological capital, food safety social co-governance, analysis of variance, *post-hoc* multiple comparisons

INTRODUCTION

Food safety is a major global public issue (1). Numerous studies have shown that it is difficult to avoid government or market failure, either alone or combined, by relying solely on the government or market, or on both government and market together to manage food safety risks. The traditional governance model has been unable to effectively meet the consumption needs of the society (2, 3). Ensuring food safety is the common responsibility of all stakeholders (4). In fact, the phenomenon of social co-governance first emerged in the 1960s and 1970s and since developed as a new governance model in Western countries. It has now become the most basic model for managing food safety risks in Western countries (5, 6). Although China has different national conditions from Western countries, the Chinese government has begun to reform the country's governance model over the last two decades, especially since 2012 (7), and the revised Food Safety Law has established social co-governance as the basic principle for managing food safety risks. At present, the academic community generally agrees that food safety social co-governance means that stakeholders, including the government, enterprises (market), social organizations, and citizens, jointly formulate or participate in the formulation of laws, regulations, and rules, coordinate and cooperate with each other, and fulfill their respective responsibilities in accordance with the law to jointly ensure food safety with low governance costs in an open, transparent, and flexible manner (8–10).

In a general sense, a citizen is a person who has citizenship and thus has certain rights as well as obligations in accordance with the laws of that country. According to Baidu Encyclopedia, it represents the concept of an individual, whereas the public is a collection of individual citizens and also includes legal persons and other organizations. Richard (11) argued that citizens are the best judges of their own behavior. Citizens capable of independent behavior are not simply food consumers. They should not only bear the responsibility of self-protection (12), but can also act as the best regulators of food safety. Following the inclusion of food safety in China's national security system in 2011, the food safety co-governance system has been gradually improved, and a consensus has gradually emerged regarding the role of social co-governance; the concept of "citizen," with its connotation of responsibilities as well as rights, reflects the internal logic of this modernization of China's national governance system and governance capabilities. As such, they are an important force in social co-governance, playing an irreplaceable role (11, 13). For example, citizens can provide tip-offs to the media and regulatory agencies, report complaints and violations, and use the media to urge the government to strengthen food safety regulation. In this way, they play a unique role in improving food safety and become an important force in social co-governance (14, 15).

Studies in Western countries have shown that individual psychological capital (PsyCap) can ignite positive emotions in citizens and motivate them to actively participate in public affairs (10, 16), thus constituting the micro-psychological foundation of food safety social co-governance (10). Unlike Western countries, food safety incidents still occur frequently in China at its current stage of development, and food safety remains one of the top concerns among Chinese citizens (17). However, at present, most Chinese citizens merely play the role of passive consumer (18), and do not actively participate in co-governance (19). Starting from the practice in Western countries and the concept of PsyCap, how can the positive emotions of Chinese citizens to participate in co-governance be ignited and their PsyCap be improved? What are the individual characteristics of citizens who have high PsyCap and will actively participate in social co-governance? These questions have not been adequately answered in the literature. To this end, this study aims to offer an exploratory introduction of the concept PsyCap and its four dimensions, establish an analytical framework for the relationship between the characteristics and PsyCap of citizens who participate in co-governance, and examine the differences in the PsyCap of citizens with different individual characteristics based on a micro-level survey. The results of this study may provide a scientific basis for understanding how to motivate citizens to actively participate in social co-governance, and thus promote the construction of a new mechanism for food safety social co-governance in China.

LITERATURE REVIEW: MEANING OF PSYCAP AND RELATIONSHIP BETWEEN PSYCAP AND CITIZEN CHARACTERISTICS

The concept of PsyCap first appeared in the economics and sociology literature. However, it was long believed that PsyCap was difficult to measure due to its instability, variability, and tendency to undergo dynamic changes (20). Only after Goldsmith et al. (21) found a correlation between an individual's PsyCap and income did PsyCap begin to be measurable, developable, and manageable. However, Goldsmith et al. (21) did not clearly define the concept of PsyCap. To address the situation whereby the field of psychology paid too much attention to human

weakness and negative psychology, Seligman (22) proposed the concept of positive psychology, trying to direct psychology research to harness the power of progress and social virtues. This groundbreaking idea triggered intense research on PsyCap and its relationship with positive behavior. Avolio et al. (23) believed that PsyCap is a positive psychological state that affects individual emotions and improves their behavior. Luthans et al. (24) further proposed the concept of positive PsyCap (referred to simply as PsyCapfor short hereafter) based on the inclusion criteria of positive organizational behavior (i.e., being positive, measurable, open to development, and performance-influencing, and having a theoretical rationale) and defined it as a positive psychological state shown by an individual in the process of growth and development. It is the core psychological element that transcends human and social capital, and is a psychological resource that promotes personal growth.

Although the concept of PsyCap has not yet been adequately studied, it can be understood from the following three perspectives based on existing research. The first perspective is trait theory, which suggests that PsyCap is an inherent trait of individuals. Hosen et al. (25) believed that PsyCap is a basic psychological quality that is durable, relatively stable, and acquired through long-term investment, such as learning. Casey and Grzywacz (26) equated PsyCap with personality, which is a result of both nature and nurture. The second perspective is state theory, which posits that PsyCap is a positive psychological state that affects individual behavior, and is a complex culmination of various individual psychological factors (27). Goldsmith (21) pointed out that PsyCap includes self-perception, attitudes toward work, ethical orientation, and general outlook on life. Tettegah (28) understood PsyCap as a complex phenomenon formed by the interaction of self-perception, attitudes toward work, ethical orientation, beliefs about life, values, and consciousness;PsyCap is seen as having the ability to change behavior by influencing an individual's psychological state. The third perspective is the synthesis theory, which suggests that PsyCap is a state-like resource and a psychological quality with characteristics of both trait and state that can be effectively developed in a specific manner. At present, synthesis theory has predominated in terms of understanding PsyCap (29).

Since the start of the twenty-first century, the study of PsyCap has been extended to the field of human resource management. Ke et al. (30) found that male employees generally had higher PsyCap than female employees, and that age and PsyCap were generally positively correlated. Fang (31) pointed out that adolescents' PsyCap increased with age. Sui et al. (32) found that individual characteristics, such as education and years of working, were correlated with PsyCap and job performance. Babalola (33) suggested that individuals with higher education were more likely to have higher levels of self-confidence and optimism. Cole et al. (34) found that individuals with higher economic income and social status had higher PsyCap. Ke et al. (35) reported that age, gender, education, and years of working all had a significant impact on the PsyCap of Chinese employees.

However, other studies have found no significant correlation between individual characteristics and PsyCap. For example, Avey (36) used 1,264 engineers from American Airlines and 524 technicians from China Telecom as comparative samples. Among the US employees, although age was shown to be correlated with PsyCap, no distinct differences in PsyCap caused by age, gender, or employment duration were observed. Among the Chinese employees, age, gender, or employment duration did not significantly affect PsyCap. Similarly, Luthans et al. (37) found no significant correlation of PsyCap with gender, age, or education. Likewise, Mathe-Soulek et al. (38) found no significant correlation between individual characteristics, such as gender and age, and PsyCap in a study of employee performance in the restaurant industry.

The above literature review discussed the nature of PsyCap in terms of trait, state, and synthesis. However, PsyCap has a very rich meaning. In terms of meaning, it is agreed that PsyCap is both a state and a trait. It is neither purely a state, like emotions, i.e., something transient, variable, and unstable, nor purely a trait, like personality and physical characteristics, which are difficult to change. Instead, it is state-like and can be developed through interventions (9–40). Moreover, the literature on PsyCap in the field of human resource management shows the existence of many relationships between PsyCap and individual characteristics of citizens; these relationships are not fixed, but vary with the public affairs and external scenarios involved. However, no answer has been provided to the question of how to measure the relationship between individual characteristics and PsyCap of citizens who participate in food safety social co-governance. Therefore, it may be worth exploring the topic to establish a framework for analyzing the relationship between characteristics and PsyCap of citizens who participate in co-governance based on their PsyCap composition.

A FRAMEWORK FOR ANALYZING THE RELATIONSHIP BETWEEN CHARACTERISTICS AND PSYCAP OF CITIZENS PARTICIPATING IN CO-GOVERNANCE

Luthans et al. (41) suggested that self-efficacy, resilience, optimism, and hope are the four most basic core elements that constitute measurable state-like PsyCap and significantly affect individual attitudes and behaviors. These factors may provide insight into developing a framework for analyzing the relationship between characteristics and PsyCap of citizens who participate in co-governance.

Stajkovic et al. (42) defined self-efficacy as "an individual's convictions (or confidence) about his or her abilities to mobilize the motivation, cognitive resources, and courses of action needed to successfully execute a specific task within a given context." According to Parker and Sharon (43), self-efficacy refers to an individual's confidence about their abilities to face challenges, do their job, and strive to succeed. In terms of food safety, as the main topic of the present study, a survey by Ovca et al. (44) showed that most students in Sloveniawere confident in handling food safely. Haapala and Probart (45) suggested that

middle school students in central Pennsylvania had high self-efficacy in food handling and food safety issues. Moreover, females had significantly higher self-efficacy than males, and this gap increased with age. Similarly, Richards and Beavers (46) found that adolescents in six southeastern US states were confident in their ability to influence food safety and exhibited strong self-efficacy. Schafer et al. (47) investigated the impact of different individual characteristics, including age, gender, marriage status, household size, employment status, education, and income, on food safety attitudes and behaviors by using them as independent variables. They found that individuals who were female, elderly, or had a large household size had higher self-efficacy and were more likely to actively participate in food safety risk management. Cater et al. (48) suggested pregnant women were highly confident in knowing how to keep foods safe for consumption based on a random survey of 222 pregnant women from Louisiana and surrounding areas in the United States. Gase et al. (49) found that increasing the availability of healthy food helped to increase people's self-efficacy regarding their ability to eat healthy.

Resilience is the ability of individuals, families, or groups to quickly recover from adversity, setbacks, and failures and actively change their mentality (50). Bestor (51) and Rosenberger (52) suggested that due to doubts about imported food, many citizens in Japanoften turn to domestic products as a safer and more reliable substitute for imported food. Khanna et al. (53) and Lutz et al. (54) found that better diet quality, which means higher intake of vegetables and fruits, was associated with higher resilience. Whatnall et al. (55) found that a healthy diet helped improve psychological health and resilience in a survey of Australian college students. That study further found that college students with an unhealthy diet had poorer psychological health than the average person. Ren (56) pointed out that individuals with higher education and income levels were more sensitive to food safety, more cautious about food safety incidents, and able to manage their panic. Wang et al. (57) found a slower recovery of consumer confidence among citizens with higher income. They suggested this may be because the consumer confidence of high-income households is more severely affected by food safety incidents and more difficult to restore due to their original higher trust in food safety. Ren and Han (58) suggested that resilience is related to occupation and that food safety incidents do not significantly change the consumption of that category of food by individuals in food-related occupations. Likewise, Li et al. (59) reported that after the 2008 melamine-tainted milk powder crisis in China, Chinese citizens with more children or lower incomes had higher resilience than those with fewer children or higher incomes and were more confident in domestic infant milk powder.

Optimism is a positive attitude toward current and future success expectations (60). Optimistic individuals have less anxiety and are more inclined to express happy emotions; positive expectations for the future indicate their inner confidence and are the source of optimism (61). Jonge et al. (62) defined individual confidence in food safety as a psychological attitude that food safety is generally controllable and will not harm their health. A series of food safety incidents in China, such as the Shineway clenbuterol crisis, the cadmium-contaminated rice incident in Hunan province, and the Shanghai Fuxi food incident, have affected the confidence of Chinese citizens in future food safety (63). Ren et al. (64) surveyed Chinese consumers of different classes and found that individuals with an older age, higher education, or higher income had a higher food safety knowledge and lower confidence in food safety in China. According to Wang and Gu (65), more than 70% of Chinese citizens believed that Western developed countries had a higher level of food safety. A survey by Cheng et al. (66) found that middle school students in Beijing were pessimistic about food safety in China. Jonge et al. (62) reported that individuals with higher education were more optimistic about food safety, but the elderly were more pessimistic. Jonge et al. (67) also found a significant positive correlation between education and optimism about food safety among Canadian and Dutch consumers.

Hope provides individuals with lasting beliefs, positive expectations, and motivation for sustained efforts to achieve their goals (68). Liu et al. (69) reported that highly-educated female citizens aged 35–54 years expressed the strongest desire for the right to know about genetically modified foods. Zhang and Zhang (70) argued that gender, age, education, income, and household size are important factors that affect individual expectations for future food safety. Nan et al. (71) found that citizens with poor health were more sensitive to food safety risks due to concerns about their own health. Ye (72) suggested that individuals with higher education and income paid more attention to health, were more willing to search for food safety information and learn how to identify safe food, and were more aware of protecting their own rights when experiencing food safety issues. Sternsdorff-Cisterna (73) found that after the end of nuclear radiation crisis in Japan, Japanese women with children were skeptical of the government's commitment to food safety and were more willing to participate in food safety risk management.

To date, few studies have directly investigated the relationship between individual characteristics and PsyCap of citizens willing to participate in co-governance. However, research in other related fields provides a useful reference for thinking about this unexplored issue. Caprara et al. (74) found that the self-efficacy of Italian voters in political participation varied with gender, age, education, and income, and that voters participated actively only when they thought they were capable of handling political affairs. Zani and Barrett (75) reached a similar conclusion, and pointed out that the enthusiasm of citizens for political participation was not only affected by individual psychological factors, but also by the macro-environment. Crocetti et al. (76) found that US youths had higher political self-efficacy and higher levels of involvement in political activities than Italian youths. Zhao et al. (77) included gender, age, marital status, and education as control variables, and found that the PsyCap of college teachers to participate in public affairs was significantly related to age and education. Wang and Jiang (78) reported that female farmers were more willing to participate in the joint management of agricultural product safety risks than male farmers. Xu et al. (79) suggested that the PsyCap of migrant workers was significantly influenced by years of education, health status, and income. Jang (80) found that government employees aged over 40 years had higher PsyCap to

participate in public affairs than younger ones. Therefore, there may be a correlation between occupation and the PsyCap to participate in social governance.

Citizens can be considered the basic unit in food safety risk management. In general, citizens have different consumption attitudes and food safety perceptions due to differences in individual characteristics such as gender, age, income, education, and household size (81, 82). Nayga (83) investigated the relationship between individual characteristics and attention to food safety and found that housewives with low education and income were more likely to perceive food safety risks. Baker (84) suggested that women and individuals with children in the household were most likely to avoid food safety risks. Flynn et al. (85) believed that gender was an important factor affecting individual perception of food safety risks. Both Dosman et al. (86) and Finke and Kim (87) confirmed the finding of Flynn et al. (85), and suggested that females were more concerned about food safety than males. Sternsdorff-Cisterna (73) reported that nearly 20% more Japanese females than males thought that nuclear radiation would cause serious harm to food safety, and thus argued that females were more willing to participate in food safety co-governance.

Dosman et al. (86) suggested that age is also a factor affecting food safety attitudes, and that the elderly are more worried about the health threats of pesticide residues in food. Roe et al. (88) pointed out that households with low income and education showed higher risk aversion and paid more attention to food safety. Wu et al. (89) believed that public perception of food safety risks is significantly related to individual characteristics such as age, gender, education, and income. According to Luthans (90), individual characteristics influence the PsyCap of citizens by acting on self-efficacy, resilience, optimism, and hope. Therefore, it can be argued that the differences in the perception and attitudes of citizens with different individual characteristics regarding food safety issues are attributable to differences in individual PsyCap. However, there are few studies that systematically examine the relationship among individual characteristics, PsyCap, and attitudes toward participation in food safety social co-governance.

In summary, numerous pioneering studies have been conducted on individual characteristics that associate with PsyCap. However, most of these studies only investigated the correlation between one or several individual characteristics and PsyCap. Studies have rarely incorporated age, income, education, marriage, occupation, gender, health status, and household size into a system to construct a collection of characteristics and comprehensively examine the correlation among several individual, family, and social characteristics in the collection and PsyCap. Furthermore, no studies have presented a complete framework for analyzing the relationship between characteristics and PsyCap of citizens. Therefore, drawing on existing literature, this study develops a 16-item scale to measure the PsyCap of citizens who participate in food safety social co-governance based on the four dimensions that are generally believed to constitute PsyCap, namely self-efficacy, resilience, optimism, and hope (90). Moreover, the scale is revised based on a pre-survey and tested for reliability and validity. On this basis, the effects of citizen characteristics on the four dimensions are analyzed using Student's *t*-test, one-way analysis of variance (ANOVA), and *post-hoc* multiple comparisons to examine the relationship between the characteristics and PsyCap of citizens who participate in food safety social co-governance. Based on the meaning and four-dimensional composition of PsyCap, this study develops the original analytical framework as shown in **Figure 1** to thoroughly examine the relationship between the characteristics and PsyCap of citizens who participate in food safety social co-governance. This framework clearly describes the process used in this study to explore ways to improve the psychological level of citizens to increase active participation in social co-governance.

SURVEY DESIGN, RESEARCH METHODS, AND SAMPLE STATISTICS AND TESTS

Sample Selection

In 2020, Wuxi in Jiangsu Province had the highest per capita GDP among all cities in China. Given the area's relatively balanced economic and social development, citizens in Wuxi show relatively high satisfaction with food safety, which provides a good foundation for this research. Primary data were collected from a field questionnaire survey in the five administrative districts (Liangxi, Xishan, Huishan, Binhu, and Xinwu) in Wuxi. The sample size in each district was proportional to the respective resident population. The survey was carried out among citizens aged over 18 years (herein after referred to as respondents) in farmers' markets and chain supermarkets with a large flow of customers. Investigators were instructed to select the third person coming into view as a respondent to ensure the randomness of sampling as much as possible (91). The questionnaires were completed anonymously by respondents at the survey sites and collected once completed. The entire survey process was completed in the period December 5–10, 2020. In total, 752 valid samples were obtained.

Questionnaire Design

A questionnaire survey provides authenticity and validity for assessing the psychological characteristics, attitudes, and behaviors of respondents (92, 93). Various classification methods have been proposed for the structure of PsyCap, mainly including two- (94), three- (21, 95), four- (96), and multi-dimensional structures (97). Among them, the four-dimensional classification method of Luthans et al. (24) has been widely accepted. According to Luthans et al. (24), psychological capital is composed of four dimensions, i.e., self-efficacy, resilience, optimism, and hope. Moreover, Luthans et al. (96) developed a questionnaire consisting of 24 items to measure PsyCap based on these four dimensions, which has been widely used in human resource management. Therefore, this study develops a scale for measuring the PsyCap of citizens who participate in food safety social co-governance, which includes four dimensional subscales in **Table 1**, drawing on the research of Luthans et al. (96) based on the analytical framework shown in **Figure 1**. Each subscale is composed of four items.

A 5-point Likert scale was used where 1 = strongly disagree and 5 = strongly agree. The higher the score, the higher the

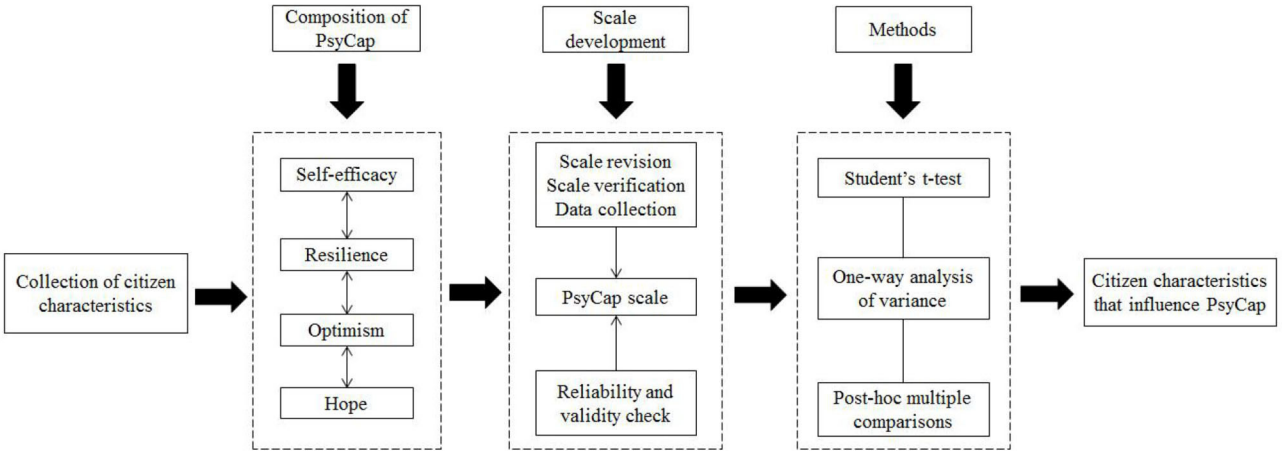


FIGURE 1 | Framework for analyzing the relationship between characteristics and PsyCap of citizens who participate in social co-governance.

TABLE 1 | Scale for PsyCap of citizens in food safety social co-governance.

Subscale	Item
Self-efficacy	1. You are confident in the safety of the food you buy.
	2. You are confident to solve food safety problems you may encounter.
	3. You cannot obtain accurate food safety information.
	4. You believe that you can contribute to joint solving of food safety problems.
Resilience	5. You learn from any food safety accidents you have experienced, if any, and improve your food safety awareness afterwards.
	6. You seek a solution calmly when encountering food problems.
	7. You take great care to avoid buying defective food products.
	8. You have to a zero-tolerance attitude toward foods with safety risks.
Optimism	9. You believe that citizens can play a role in food safety risk management.
	10. You believe that the quality of the vast majority of food in the market is guaranteed.
	11. You believe that food safety is better now than in the past.
	12. You believe that food safety will be better in the future.
Hope	13. You believe that it is meaningful to participate in food safety social co-governance.
	14. You believe that food safety will be better in the future despite the persistent occurrence of food safety incidents at present.
	15. You will actively learn food safety knowledge to protect your dietary health.
	16. You believe that there will be better solutions to food safety issues in the future.

PsyCap, except for Item 3, which has reverse scoring. The characteristic variables and their values are presented in **Table 2**.

Analysis Methods

Data were processed using SPSS 24.0 software. Mean difference was used to analyze the association between different individual characteristics and the PsyCap of citizens who participate in food safety social co-governance. Student's *t*-test was used for dichotomous categorical variables and ANOVA for multichotomous variables. A significant *F*-value from ANOVA indicates that there are significant differences in the means of the dependent variable between at least two categories of the independent variable. In this case, *post-hoc* multiple comparisons were performed to determine which categories yielded the significant differences (98). *Post-hoc* multiple comparisons are used to compare the means of three or more categories to further determine the differences between each two categories (99). *Post-hoc* comparisons were performed *via* the least significant difference (LSD) test when the homogeneity of variance assumption was met. Otherwise, Tamhane's T2-test was employed.

Demographics of Respondents

Respondent demographics are presented in **Table 3**. In terms of gender composition, there were more females than males, which is consistent with the fact that in China, most household food purchasers are female. Most respondents were aged 26–45 (66.09%), married (70.48%), company employees (44.28%), and in good health (89.76%). In addition, most had a household size of 3 (55.98%), a bachelor's degree (40.96%), and a personal annual income of more than 100,000 yuan (26.46%). Finally, most had no children aged under 18 (50.27%) or pregnant woman (93.22%) in their households. It should be noted that the demographics of the sample do not perfectly match the overall demographics of Wuxi due to the higher number of females surveyed than males. However, this does not compromise the representativeness of the survey sample because household food is mostly purchased by one or some family members, who are generally female. Given the sampling method used, i.e., surveying carried out at the point of purchase of food, this sample distribution therefore reflects food purchase behavior in the study area. In fact, the demographics of the study's sample are consistent with those of Wu et al. (100) and

TABLE 2 | Independent variables.

Variable	Value	Mean	Standard deviation
Gender	Male = 1; female = 2	1.52	0.500
Age	18–25 years = 1; 26–35 years = 2; 36–45 years = 3; 46–55 years = 4; 56 years and older = 5	2.46	1.017
Marital status	Married = 1; unmarried = 2	1.30	0.456
Household size (n)	1 person = 1; 2 persons = 2; 3 persons = 3; 4 persons = 4; 5 persons and more = 5	3.34	0.854
Education	Junior high school or lower = 1; high school = 2; junior college = 3; bachelor's degree = 4, master's degree or higher = 5	3.33	1.107
Personal annual income	36,000 yuan or lower = 1; 36,000–50,000 yuan = 2; 50,000–80,000 yuan = 3; 80,000–100,000 yuan = 4; 100,000 yuan or higher = 5	3.19	1.469
Having children aged under 18 in the household	No = 1; Yes = 2	1.50	0.500
Having a pregnant woman in the household	No = 1; Yes = 2	1.07	0.252
Health status	Good = 1; fair = 2; poor = 3	1.11	0.349
Occupation	Government or public institution employee = 1; company employee = 2; farmer = 3; school students = 4; others = 5	2.74	1.328

Wu et al. (101), which are previous studies conducted in the same survey area as this study. However, readers should assess the results of this study based on consideration of data representativeness.

Sample Tests

Reliability Test

Scale reliability indicates the consistency of results from repeated measurements obtained by the same evaluators in similar situations. The higher the consistency, the higher the reliability. Cronbach's alpha was used to assess the reliability of the scale developed in this study. In general, a Cronbach's alpha of >0.8, >0.7, and >0.6 represents very good, good, and acceptable reliability, respectively. However, if the value is below 0.6, the scale needs to be revised (102). As shown in **Table 4**, the Cronbach's alpha values of the PsyCap scale developed in this study, and its subscales for each dimension, i.e., self-efficacy, resilience, optimism, and hope, are 0.750, 0.631, 0.677, 0.653, and 0.701, respectively, all of which are higher than 0.6. Thus, the scale can be considered reliable.

Validity Test

The four PsyCap dimensions of self-efficacy, resilience, optimism, and hope involve many variables, which are correlated among themselves. These interrelationships not only increase the complexity of analysis, but also result in an overlap in the information reflected by the observation data. Therefore, factor analysis was used to extract common factors from the many variables (103). The Kaiser-Meyer-Olkin (KMO) test of sampling adequacy and Bartlett test of sphericity were used to determine whether the PsyCap scale developed in this study satisfies the requirements of factor analysis. According to Kaiser and Rice (104), if a KMO value >0.8, between 0.7 and 0.8, or between 0.6 and 0.7 is obtained, it would be very suitable, suitable, and barely suitable to conduct factor analysis. If the KMO value is below 0.6, it is not suitable to conduct factor analysis. As shown in **Table 5**, the KMO value of the PsyCap scale was 0.780, indicating that there are many common factors among variables and it would be suitable to conduct factor analysis. The significance (p) of Bartlett test of sphericity is <0.001, indicating that the variables are correlated, which also justifies the use of factor analysis.

The structural validity of a questionnaire indicates the degree of correspondence between a certain structure reflected in the measurement results and the measured values. Factor analysis is an ideal method to assess the structural validity of questionnaires (105). According to Comrey and Lee (106), a questionnaire must meet all three following criteria to have acceptable structural validity: (a) the factor loadings of each item in its own factor should be at least 0.450, (b) those in other factors should be <0.320, and (c) there are at least three items for each factor. Because the PsyCap scale has four dimensions, principal component analysis with four factors and varimax rotation was performed. As can be seen from **Table 6**, the four common factors explain 51.674% of the variance, the four factors with 16 items have acceptable structural validity, and each item can represent the corresponding factor.

RESULTS

Empirical Results for the Values of PsyCap and Its Four Dimensions

The PsyCapvalues of citizens who participate in co-governance and its four dimensions were calculated based on the 16 items measuring the four dimensions of PsyCap given in **Table 1**. As shown in **Table 7**, the mean values of the four dimensions are in a favorable range. Accordingly, following Luthans et al. (96), it can be concluded that the respondents had relatively high levels of self-efficacy, resilience, optimism, and hope, and thus high overall PsyCap.

TABLE 3 | Demographics of respondents.

Demographic	Category index	Sample size (*n*)	Proportion (%)
Gender	Male	358	47.61
	Female	394	52.39
Age	18–25 years	143	19.02
	26–35 years	252	33.51
	36–45 years	245	32.58
	46–55 years	92	12.23
	56 years or older	20	2.66
Marital status	Married	530	70.48
	Unmarried	222	29.52
Household size (*n*)	1	13	1.73
	2	63	8.38
	3	421	55.98
	4	167	22.21
	5 or more	88	11.70
Education	Junior high school or lower	60	7.98
	High school (including vocational high school)	111	14.76
	Junior college (including higher vocational colleges)	187	24.87
	Bachelor's degree	308	40.96
	Master's degree or higher	86	11.44
Personal annual income	<36,000 yuan	144	19.15
	36,000–50,000 yuan	120	15.96
	50,000–80,000 yuan	133	17.69
	80,000–100,000 yuan	156	20.74
	More than 100,000 yuan	199	26.46
Having children aged under 18 in the household	No	378	50.27
	Yes	374	49.73
Having a pregnant woman in the household	No	701	93.22
	Yes	51	6.78
Health status	Poor	8	1.06
	Fair	69	9.18
	Good	675	89.76
Occupation	Government or public institution employee	119	15.82
	Company employee	333	44.28
	Farmer	26	3.46
	Student	98	13.03
	Others	176	23.40

Empirical Results on the Correlation Between the Characteristics and PsyCap of Citizens

The one-way ANOVA results for PsyCap are shown in **Table 8**, **Supplementary Table 1**. Significant *F*-values were observed for education ($F = 2.942$, $p = 0.020$), annual income ($F = 3.452$, $p = 0.008$), and health status ($F = 4.848$, $p = 0.008$). Moreover, the homogeneity of variance assumption was met for annual income ($p < 0.05$), but not for education or health status ($p > 0.05$). Therefore, the Tamhane's T2 test was performed for annual income and the LSD test for education and health status for *post-hoc* multiple comparisons. As shown in **Table 9**, citizens with high school, bachelor's degree, master's degree, or higher education had significantly higher PsyCap to participate in food safety co-governance than those with junior high school or lower education. Citizens with an annual income of 50,000–80,000 yuan or more than 100,000 yuan had significantly higher PsyCap than those with an annual income of 36,000 yuan or less. Citizens in good health had significantly higher PsyCap than those in fair health. Further analysis can be performed using the four dimensions of PsyCap.

TABLE 4 | Reliability of the PsyCap scale.

Dimension	Cronbach's alpha of subscale	Cronbach's alpha of full scale
Self-efficacy	0.631	0.750
Resilience	0.677	
Optimism	0.653	
Hope	0.701	

TABLE 5 | KMO test and Bartlett test of sphericity of the PsyCap Scale.

KMO test		0.780
Bartlett test of sphericity	Approximate chi-square	2188.322
	Degree of freedom	120
	Significance	0.000

Citizen Characteristics and Self-Efficacy

As shown in **Supplementary Table 1**, results of the Student's *t*-test indicated significantly higher self-efficacy ($t = -2.386$, $p = 0.017$) for females than for males, indicating that females had higher self-efficacy for participating in co-governance. A significant *F*-value was obtained for annual income ($F = 5.287$, $p = 0.000$) in the one-way ANOVA for self-efficacy. However, as shown in **Table 2**, annual income includes five different levels and met the homogeneity of variance assumption ($p < 0.05$). Therefore, the Tamhane's T2 test was performed for *post-hoc* multiple comparisons to determine the association between different levels of annual income and self-efficacy. As shown in **Table 9**, significantly higher self-efficacy was observed in citizens with an annual income of 50,000–80,000 yuan than in those with an income of 36,000–50,000 yuan, and also in those with an income of 50,000–100,000 yuan than in those with an income of 36,000 yuan or less. A significant *F*-value was also obtained for health status ($F = 3.140$, $p = 0.044$). Health status includes three different levels and did not meet the homogeneity of variance assumption ($p = 0.170$). Therefore, the LSD test was performed for *post-hoc* multiple comparisons. As shown in **Table 8**, citizens in good health had significantly higher self-efficacy than those in fair health.

TABLE 6 | Rotated factor loading matrix.

Item	Mean	Standard deviation	Factor			
			1	2	3	4
1. You are confident in the safety of the food you buy.	3.49	0.772	0.753			
2. You are confident to solve food safety problems you may encounter.	3.34	0.840	0.788			
3. You cannot obtain accurate food safety information.	3.47	0.976	0.595			
4. You believe that you can contribute to joint solving of food safety problems.	3.57	0.843	0.586			
5. You learn from any food safety accidents you have experienced, if any, and improve your food safety awareness afterwards.	3.09	1.006		0.725		
6. You seek a solution calmly when encountering food problems.	3.60	0.861		0.737		
7. You take great care to avoid buying defective food products.	3.88	0.991		0.648		
8. You have to a zero-tolerance attitude toward foods with safety risks.	3.64	0.920		0.678		
9. You believe that citizens can play a role in food safety risk management.	3.43	0.916			0.622	
10. You believe that the quality of the vast majority of food in the market is guaranteed.	3.75	0.824			0.697	
11. You believe that food safety is better now than in the past.	3.54	0.888			0.734	
12. You believe that food safety will be better in the future.	3.66	0.860			0.649	
13. You believe that it is meaningful to participate in food safety social co-governance.	3.98	0.837				0.748
14. You believe that food safety will be better in the future despite the persistent occurrence of food safety incidents at present.	3.72	0.814				0.659
15. You will actively learn food safety knowledge to protect your dietary health.	3.86	0.826				0.758
16. You believe that there will be better solutions to food safety issues in the future.	3.68	0.897				0.623

Citizen Characteristics and Resilience

As shown in **Table 8**, a significant *F*-value was obtained for health status ($F = 6.623$, $p = 0.001$) in the one-way ANOVA for resilience. However, the homogeneity of variance assumption was not met ($p = 0.510$). Therefore, the LSD test was performed for *post-hoc* multiple comparisons. As shown in **Table 9**, citizens in good health had significantly higher resilience than those in fair health.

Citizen Characteristics and Optimism

As shown in **Table 8**, a significant *F*-value was obtained for education ($F = 5.240$, $p = 0.000$) in the one-way ANOVA for optimism. However, optimism includes five different levels and did not meet the homogeneity of variance assumption ($p = 0.685$). Therefore, the LSD test was performed for *post-hoc* multiple comparisons. As shown in **Table 9**, significantly higher optimism was observed in citizens with bachelor's degree than in those with lower educational attainment, and also in those with master's degree or higher than in those with junior high school or lower education.

TABLE 7 | Empirical results for PsyCap and its four dimensions.

PsyCap and its four dimensions	Min	Max	Mean	Standard deviation
PsyCap	1.81	4.75	3.6061	0.40466
Self-efficacy	1.25	5.00	3.4684	0.59297
Resilience	1.25	5.00	3.5519	0.67431
Optimism	1.25	5.00	3.5947	0.61122
Hope	1.75	5.00	3.8095	0.61308

Citizen Characteristics and Hope

As shown in **Table 8**, significant *F*-value were obtained for education ($F = 5.240$, $p = 0.000$) and annual income ($F = 4.197$, $p = 0.002$) in the one-way ANOVA for hope. Moreover, the homogeneity of variance assumption was met for both variables ($p > 0.05$). Therefore, the Tamhane's T2 test was performed for *post-hoc* multiple comparisons for both variables. As shown in **Table 9**, significantly higher hope was observed in citizens with high school, junior college, or a bachelor's degree than in those with junior high school or lower education, and also in those with

TABLE 8 | Results for one-way analysis of variance about individual characteristics of citizens who will actively participate in food safety social co-governance.

Variables	Analysis of variance			
	Levene statistic	Significance	*F*-value	Significance
PsyCap				
Education	1.881	0.112	2.942	0.020*
Personal annual income	3.213	0.013	3.452	0.008**
Health status	0.250	0.779	4.848	0.008**
Self-efficacy				
Personal annual income	4.512	0.001	5.287	0.000***
Health status	1.775	0.170	3.140	0.044*
Resilience				
Health status	0.674	0.510	6.623	0.001**
Optimism				
Education	0.569	0.685	5.240	0.000***
Hope				
Education	4.802	0.001	5.370	0.000***
Personal annual income	3.245	0.012	4.197	0.002**

*, **, and *** indicate $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

an annual income of more than 100,000 yuan than in those with an annual income of 50,000 yuan or less.

CONCLUSIONS AND PROSPECTS

Conclusions

This paper has introduced the concept of analyzing PsyCap and its four dimensions and developed a framework for analyzing the relationship between characteristics and PsyCap of citizens willing to participate in food safety social co-governance. Moreover, the 10 most important individual characteristics associating with this behavior, including gender, age, marriage, household size, education, annual income, having children aged under 18 in the household or not, having a pregnant woman in the household or not, health status, and occupation, were identified. On this basis, the PsyCap of citizens with different individual characteristics willing to participate in co-governance was empirically examined based on a survey using Student's *t*-test, one-way ANOVA, and *post-hoc* multiple comparisons. The empirical results show that age, marriage, household size, having children aged under 18 in the household or not, having a pregnant woman in the household or not, and occupation had no significant correlation with any of the four dimensions of PsyCap. Therefore, these individual characteristics are ineffective in influencing the PsyCap of citizens to encourage them to participate in co-governance. The other four individual characteristics, including annual income, education, health status, and gender, are not significantly correlated with all dimensions of PsyCap, and have different associations with PsyCap. The main conclusions are summarized below.

First, gender is only significantly correlated with self-efficacy for participating in co-governance. Specifically, females have higher self-efficacy for participating in food safety co-governance. This is consistent with the findings of Schafer et al. (47) and Haapala and Probart (45). However, gender does not significantly associate with the PsyCap of citizens to encourage participation in co-governance.

TABLE 9 | *Post-hoc* multiple comparisons.

Variable	*I*	*J*	MD (*I-J*)	*P*
PsyCap	Junior high school or lower	High school	−0.13882	0.032*
		Bachelor's degree	−0.17453	0.002**
		Master's degree or higher	−0.13370	0.049*
	36,000 yuan or less	50,000–80,000 yuan	−0.13829	0.022*
		More than 100,000 yuan	−0.13523	0.013*
	Good health	Fair health	0.15056	0.003**
Self-efficacy	36,000 yuan or less	50,000–80,000 yuan	−0.26006	0.001**
		80,000–100,000 yuan	−0.20232	0.016*
	36,000–50,000 yuan	50,000–80,000 yuan	−0.25277	0.013*
	Good health	Fair health	0.17870	0.017*
Resilience	Good health	Fair health	0.29562	0.001**
Optimism	Bachelor's degree	Junior high school or lower	0.28415	0.001**
		High school	0.16804	0.012*
		Junior college	0.18296	0.001**
	Master's degree or higher	Junior high school or lower	0.27897	0.006**
Hope	More than 100,000 yuan	36,000 yuan or less	0.24082	0.002**
		36,000–50,000 yuan	0.22346	0.033*
	Junior high school or lower	High school	−0.26329	0.030*
		Junior college	−0.25174	0.032*
		Bachelor's degree	−0.37760	0.000***

*, **, and *** indicate $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

Second, annual income is significantly correlated with self-efficacy and hope for participating in co-governance, but it does not significantly associate with resilience or optimism. In this study, significantly higher self-efficacy was observed in citizens with an annual income of 50,000–80,000 yuan than in those with 36,000–50,000 yuan, and also in those with an income of 50,000–100,000 yuan than in those with an income of 36,000 yuan or less. This is similar to the findings of Caprara et al. (74) and Zani and Barrett (75). Significantly higher hope was observed in citizens with an annual income higher than 100,000 yuan than in those with an income of 50,000 yuan or less. This is similar to the findings of Ye (72). Annual income associates with PsyCap through self-efficacy and hope. Moreover, citizens with an annual income of 50,000–80,000 yuan and more than 100,000 yuan had higher PsyCap to participate in co-governance than those with an income of 36,000 yuan or less. This is similar to the conclusions of Cole et al. (34) and Xu et al. (79).

Third, education is significantly correlated with optimism and hope for participating in co-governance, but it does not significantly associate with self-efficacy or resilience. In this study, significantly higher optimism was observed in citizens with a bachelor's degree than in those with lower educational attainment, and also in those with a master's degree or higher than in those with junior high school or lower education. This is similar to the conclusion of Jonge et al. (67). Significantly higher hope was observed in citizens with high school, junior college, or a bachelor's degree than in those with junior high school or lower education. This is similar to the findings of Liu et al. (69) and Babalola (33). Moreover, citizens with high school, bachelor's degree, and master's degree or higher education had significantly higher PsyCap than those with junior high school or lower education. This is similar to the conclusion of Xu et al. (79).

Lastly, health status is significantly correlated with self-efficacy and resilience for participating in co-governance, but it does not significantly associate with optimism or hope. In this study, citizens in good health had significantly higher self-efficacy and resilience than those in fair health. This is similar to the findings of Gase et al. (49) and Lutz et al. (54). Moreover, citizens in good health had higher PsyCap to participate in co-governance than those in fair health. This is similar to the findings of Xu et al. (79).

Previous studies have confirmed that many individual, family, and social characteristics associate with one or more dimensions of citizens' PsyCap as well as overall PsyCap. However, based on a survey in Wuxi, Jiangsu Province, this study reveals that citizens are likely to actively participate in food safety social co-governance only when they have at least one of three characteristics: (a) higher than average income in their city of residence; (b) a bachelor's degree or higher education; or (c) good health. Therefore, motivating citizens to participate in co-governance is a long-term process in China. The fundamental strategy is to (1) develop the economy and increase citizens' incomes, especially low-income groups (for example, increasing the minimum subsistence allowance for low-income groups and especially increasing central and provincial fiscal transfer payments to relatively poor rural areasto increase incomes in these areas); (2) promote education, especially higher education, to improve food safety literacy of the public (for example, by improving compulsory education in relatively poor rural areas and providing as many affordable and practical education and training opportunities as possible to low-income workers); and (3) implement more progressive health policies to improve sanitation and public health. In the short term, it may be effective to strive to increase the income of low-income groups, implement popular education about food safety knowledge, and promote healthy dietary habits and lifestyles.

Prospects

This study does have some limitations. Due to the lack of a validated scale for measuring the PsyCap of citizens to participate in food safety social co-governance, the reliability, and validity of the scale developed in this study requires further investigation. In addition, the sample for this study was limited to citizens in Wuxi, and the demographics of the sample do not perfectly match the overall demographics of Wuxi[1]. Therefore, further research is required to confirm the findings this study. It is hoped that the methods, conclusions, and policy recommendations of this case study on Wuxi can be promoted across China and provide guidance at the national level. More broadly, it is hoped that the experience of China may provide lessons and insights for other developing countries.

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.

ETHICS STATEMENT

Ethical approval for this study and written informed consent from the participants of the study were not required in accordance with local legislation and national guidelines. All data were de-identified and the article does not contain any individual person's data. Therefore, this study was exempted from ethics approval.

AUTHOR CONTRIBUTIONS

LW conceptualized the study. KQ processed and analyzed the relevant data, as well as wrote the draft manuscript. XC collected and analyzed the relevant data, wrote, and revised the manuscript. All authors contributed to the study design, interpretation the results and manuscript revision, and have approved the final manuscript.

FUNDING

This study was supported by the National Social Science Fund of China: Research on social co-governance of food safety risks and cross-border cooperative governance mechanism (20&ZD117).

ACKNOWLEDGMENTS

The authors acknowledge the contributions of the editors and reviewers.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.772117/full#supplementary-material

[1]The demographics of the sample for this study differed from those of the urban population of Wuxi, and, of course, could not represent the overall demographics of China. Therefore, readers should assess the results of this study based on consideration of data representativeness.

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frontiers in Public Health

ORIGINAL RESEARCH
published: 30 November 2021
doi: 10.3389/fpubh.2021.737788

A Game Model for Medical Service Pricing Based on the Diagnosis Related Groups

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Background: Currently there are various issues that exist in the medical institutions in China as a result of the price-setting in DRGs, which include the fact that medical institutions tend to choose patients and that the payment standard for complex cases cannot reasonably compensate the cost.

Objective: The main objective is to prevent adverse selection problems in the operations of a diagnosis-related groups (DRGs) system with the game pricing model for scientific and reasonable pricing.

Methods: The study proposes an improved bargaining game model over three stages, with the government and patients forming an alliance. The first stage assumes the alliance is the price maker in the Stackelberg game to maximize social welfare. Medical institutions are a price taker and decide the level of quality of medical service to maximize their revenue. A Stackelberg equilibrium solution is obtained. The second stage assumes medical institutions dominate the Stackelberg game and set an optimal service quality for maximizing their revenues. The alliance as the price taker decides the price to maximize the social welfare. Another Stackelberg equilibrium solution is achieved. The final stage establishes a Rubinstein bargaining game model to combine the Stackelberg equilibrium solutions in the first and second stage. A new equilibrium between the alliance and medical institutions is established.

Results: The results show that if the price elasticity of demand increases, the ratio of cost compensation on medical institutions will increase, and the equilibrium price will increase. The equilibrium price is associated with the coefficient of patients' quality preference. The absolute risk aversion coefficient of patients affects government compensation and total social welfare.

Conclusion: In a DRGs system, considering the demand elasticity and the quality preference of patients, medical service pricing can prevent an adverse selection problem. In the future, we plan to generalize these models to DRGs pricing systems with the effects of competition of medical institutions. In addition, we suggest considering the differential compensation for general hospitals and community hospitals in a DRGs system, in order to promote the goal of hierarchical diagnosis and treatment.

Keywords: bargaining model, pricing, government compensation, medical service, patient, quality

OPEN ACCESS

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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *07 July 2021*
Accepted: *05 October 2021*
Published: *30 November 2021*

Citation:
Duan J, Lin Z and Jiao F (2021) A Game Model for Medical Service Pricing Based on the Diagnosis Related Groups. Front. Public Health 9:737788. doi: 10.3389/fpubh.2021.737788

INTRODUCTION

The National Health Commission and the other relevant departments in China have started to test the diagnosis-related groups (DRGs) system in 30 pilot locations since 2019. DRGs refer to a price standardization mechanism based on patients' classification. Patients can be classified based on their demographic and medical information, such as age, gender, length in hospital, types of diseases, the severity of diseases and comorbidity, complications, the necessity of surgery, etc (1). DRGs aim to categorize patients who have similar clinical features and medical resource consumption into the same groups, which can standardize prospective payment to hospitals or other medical institutions (2).

Currently there are various issues that exist in medical institutions around the world as a result of the price-setting in DRGs, which include the fact that medical institutions tend to choose patients, the payment standard for complex cases cannot reasonably compensate the cost, and medical service providers increase the amount of outpatient services in order to reduce hospitalization expenses (3). High price-setting in DRGs leads to the difficulty of the government controlling medical expenses, while low price-setting is not able to fairly compensate the costs in medical institutions (1), and even leads to hospitals refusing to accept patients in critical conditions. This conflict in price-setting can be understood as a problem of adverse selection (4). Therefore, it is imperative to explore an optimal pricing system that helps to resolve the problem of adverse selection.

Many scholars apply the game theory to the pricing of medical services, which solves the conflict of interests of the stakeholders in the pricing of medical services (5–10). For example, Weingarten (11) applies a generalized game theory model to study the price-setting strategy of competitive medical institutions. Westhoff et al. (5) and Agee et al. (8) apply game theory to study cooperation and competition in disease treatment payment and compensation. Nagurney (12) focus on the supply chain of blood products in an asymmetric information environment. Their study determines a generalized Nash equilibrium model by adopting sharing constraints. This model discusses the price-setting problem in the blood products supply chain, which finds that participants nearer the termination of the supply chain will have better access to information and stronger bargaining power. However, most of these studies focus on the linkages between price makers and medical institutions' behavior, which ignore the impact on medical buyers' behavior and patient preferences with regard to medical service quality.

The present study thus aims to address the above issues by providing some improvements in the game theoretical model assumptions and the model design. First, the quality of medical service is introduced as a variable in a medical service pricing game model. Second, in China, medical institutions are monopolistic in the provision of medical services, and they are in a dominant position in the negotiation of price and quality. Patients as individuals, their bargaining power is scattered. Moreover, the lack of professional knowledge and complete information also weaken patients' bargaining power. Therefore, it is necessary for the government, as the co-payer of medical services, to balance the power of the supplier and the purchasers.

We design a DRG pricing and compensation model as a composite model of two Stackelberg games and bargaining games. In the first round of the game, with the alliance of government and patients as the leader of the game and the medical institutions as the game follower, we get an equilibrium solution about the price and quality of medical services. In the second round of the game, with the medical institutions as the leader of the game and the alliance of government and patients as the follower of the game, we get another equilibrium solution about the price and quality of medical services. In the third round of the game, the two equilibrium solutions obtained above are used as the initial solution of the bargaining game, and the government and patients share the medical expenses.

RELATED WORKS

In the early days, scholars generally considered the competitiveness of the medical service market and established a game pricing model. The Shleifer pricing mechanism is a type of yardstick regulation developed by Shleifer (13). They show that the specific Nash equilibrium is the point where medical institutions achieve optimal marginal cost. Ellis and McGuire (14) explore an optimal neutral risk situation for medical insurance paying to medical institutions. Allen and Gertler (15) use game theory to study the influence of price-setting strategy on patients' satisfaction with services. Weingarten (11) applies a generalized game theory model to study the price-setting strategy of competitive medical institutions. Westhoff et al. (5) and Agee et al. (8) apply game theory to study cooperation and competition in disease treatment payment and compensation. Robinson (16) adopt a Stackelberg game theory model in discussing the relationship between cost transfer and payment methods for medical institutions. They reveal a direct connection between the cost-shifting and medical service payment policy, which shows paying by classification of diseases is better than paying by medical service items.

Many other scholars develop game models on price-setting and negotiation by multiple participants in the medical services. Most of these studies are based on information asymmetry between participants (17, 18). Yaesoubi and Roberts (19) develop a game model that considers two types of constraints. The needed constraint is the bargaining powers of medical service purchasers, and the soft constraint is the cost reimbursement for service providers. These two types of constraints help the model better determine the pricing in an information asymmetric environment. De (20) adopts game theory to examine the impact of information transactions on the relationship between medical institutions and patients, and finds that there will be a Nash equilibrium when patients can restrict medical suppliers' induced demand.

In recent years, scholars have focused on the influence of various factors, such as government intervention (21, 22), medical service quality (17, 23–25), and payment mode of medical services (26, 27), on the results of pricing games

(2, 28–30). Behzad and Jacobson (31) investigate the impact of government price intervention and duopoly competition on medical price-setting. Their study applies the asymmetric Bertrand-Edgeworth model to study this impact within a duopoly market. A similar study developed by das Chagas Moura et al. (32), who apply queue theory to improve the Stackelberg game model, focuses on the problems of medical service pricing and medical quality. Koenecke (33) analyses the non-extreme equilibrium between two different payment methods in medical insurance and medical institutions by applying a Stackelberg game model. These two payment methods include a charge on a per-service basis and a per-patient basis. Assuming medical insurance can offer non-linear bonuses, the analysis shows that charges on a per-patient basis can better contribute to sharing medical service information between medical institutions and patients.

THE NOVEL BARGAINING GAME MODEL

Model Assumptions

Assuming there are three players in the medical service market, including the government, medical service suppliers, and patients. Patients have only one treatment demand on each type of disease and pay for a certain ratio of treatment fee to acquire effective medical services. Medical institutions can solve patients' queuing problems by having an appointment booking system. As payers of medical service, the government and patients form an alliance.

Assuming medical institutions have sufficient ability to fulfill patients' demands, the decision variable of the alliance is the treatment price of each disease, and the objective function is total social welfare. The decision variable of medical institutions is medical service quality, and the objective function is the profit of medical service. If assuming the demand function of a medical service is a linear function of the medical service price and quality, which is $Q = a - bp + cq$, where $a, b, c \geq 0$, b is the price elasticity of demand (PED) for a single type of disease, c is the coefficient of patients' preference on quality, and p and q are decision variables. Moreover, the cost function of a medical service is a function of the medical service quality, which is $C = F + \frac{1}{2}\gamma q^2 Q$, where F is the fixed cost of medical service, $\frac{1}{2}\gamma q^2 Q$ is the marginal cost, and γ is the coefficient of quality cost.

The objective function of the alliance is the social total surplus, which refers to consumer surplus plus producer surplus.

$$\begin{aligned} WF &= \int_0^Q \frac{a+cq-Q}{b} dQ - pQ + pQ - F - \frac{1}{2}\gamma q^2 Q \\ &= \int_0^Q \frac{a+cq-Q}{b} dQ - F - \frac{1}{2}\gamma q^2 Q \end{aligned} \tag{1}$$

And the utility of patients is

$$Up = \int_0^Q \frac{a+cq-Q}{b} dQ - pQ \tag{2}$$

The profit of medical institutions is

$$\pi = pQ - F - \frac{1}{2}\gamma q^2 Q \tag{3}$$

Model Formation

The bargaining game on disease treatment pricing will be developed between the alliance and the medical institutions. In the first stage, the alliance will be a price maker and determine a pricing strategy for treatment based on social welfare maximization. Medical institutions will the price taker to determine a service quality strategy for responding to the price strategy from the alliance. A Stackelberg equilibrium solution will be achieved to balance the treatment price and service quality. In the second stage, medical institutions will be the price maker and determine an optimal service quality strategy for maximizing their profits. While the alliance as the price taker will determine another optimal treatment price strategy based on social welfare maximization in response to the medical institutions' strategy. Another Stackelberg equilibrium solution will be achieved in this stage to balance treatment price and service quality. These two equilibrium solutions will be an initial solution for the bargaining model between the alliance and medical institutions in the final stage. The model will be in the Stackelberg game based on the bargaining power of each player and it will achieve a final Stackelberg bargaining equilibrium solution.

The First Round Stackelberg Game

The first stage is to apply the Stackelberg model to analyze the pricing behavior by the alliance as a price maker. Based on social total surplus maximization, the alliance can determine a price p_1 for a certain medical treatment, and medical institutions as price takers will determine a maximum profit on this certain treatment which is q_1 based on p_1.

By applying the reverse acquisition, firstly, when maximizing the medical institutions' profit,

$$\frac{\partial \pi}{\partial q_1} = \frac{\partial (p_1 Q - F - \frac{1}{2}\gamma {q_1}^2 Q)}{\partial q_1} = 0 \tag{4}$$

And we obtain:

$$q_1 = \frac{r b_1 p_1 - ar + \sqrt{(r b_1 p_1 - ar)^2 + 6c^2 r p_1}}{3cr} \tag{5}$$

Plugging (5) into (1), where the utility function maximization for the alliance will be:

$$\frac{\partial WF}{\partial p_1} = \frac{\partial (\int_0^Q \frac{a+cq_1-Q}{b} dQ - F - \frac{1}{2}\gamma {q_1}^2 Q)}{\partial p_1} = 0 \tag{6}$$

We then have the following:

$$p_1 = \frac{\gamma^2 b^2}{9c^2} + \frac{\gamma b - 2a - 3}{3b} \tag{7}$$

Plugging (7)into (5) and we get:

$$q_1 = \frac{b\gamma \sqrt{(a\gamma - b)^2 - 6c^2}}{3ac} \tag{8}$$

Lemma 1. *if and only if* $F \geq \frac{b(a+\gamma^2)}{ac-\gamma}$, *there is an equilibrium solution that exists for the pricing and quality Stackelberg game model between the alliance and medical institutions, and this equilibrium solution is* $p_1 = \frac{\gamma^2 b^2}{9c^2} + \frac{\gamma b - 2a - 3}{3b}$, $q_1 = \frac{b\gamma\sqrt{(a\gamma-b)^2-6c^2}}{3ac}$

The ratio between the fixed cost and marginal cost in medical institutions will be the minimum level of government compensation, and it will be a positive relationship with PED. In other words, when the PED of a certain disease treatment increases, the ratio of cost compensation on medical institutions will increase, and the treatment price will increase. Whereas, when the ratio of cost compensation on medical institutions decreases, the treatment price will decrease. This is the opposite of Ramsey pricing because of the welfare in medical services. When a type of disease belongs to the basic medical service, PED decreases and the ratio of compensation on medical services will decrease. While if a type of disease is not listed as a basic medical service, such as rehabilitation, when PED increases, the ratio of compensation on medical services will increase.

The Second Round Stackelberg Game

In this round of Stackelberg games, medical institutions are the first decision-makers, and the government and patients' alliance are the followers. Based on the objective of profit maximization, medical institutions will determine the decision variable q_2 for optimizing the service quality. The alliance then determines an optimal price p_2 for responding to the decision by the medical institutions. By applying the reverse acquisition, a price for the alliance can be obtained, which guarantees a maximized utility. Based on $\partial WF/\partial p_2 = 0$, it can achieve

$$p_2 = \frac{1}{2}cq_2{}^2 + \frac{cq_2 + a - 1}{b} \tag{9}$$

Plugging (9)into (3), based on $\frac{\partial \pi}{\partial q_2} = 0$, it can achieve

$$q_2 = \frac{bc\sqrt{a\gamma - b + 6\gamma^2}}{3a} \tag{10}$$

Plugging (10) into (9), it can achieve

$$p_2 = \frac{1}{2}b^2c^3\frac{a\gamma - b + 6\gamma^2}{9a^2} + c^2\sqrt{a\gamma - b + 6\gamma^2} + \frac{a-1}{b} \tag{11}$$

Lemma 2. *if and only if* $\sqrt{\frac{\gamma^2 - a\gamma}{4a}} < c < \sqrt{\frac{\gamma^2 + a\gamma}{4a}}$, *there is an equilibrium solution that exists in the Stackelberg game on the pricing and quality for the alliance and medical institutions. This solution is as follows:*

$$p_2 = \frac{1}{2}b^2c^3\frac{a\gamma - b + 6\gamma^2}{9a^2} + c^2\sqrt{a\gamma - b + 6\gamma^2} + \frac{a-1}{b},$$
$$q_2 = \frac{bc\sqrt{a\gamma - b + 6\gamma^2}}{3a}$$

If the coefficient of patients' quality preference is in a certain range, the equilibrium price of disease treatment will increase with the increasing of the coefficient of patients' quality preference. Because the larger the coefficient of patients' quality preference, the more competitive medical service quality is, and that is, if a medical institution slightly improves the quality of medical services, it will lead to a large increase in the demand for medical services. This will also lead to an increase in the market share, which brings more profits to medical institutions. In this regard, medical institutions normally set their treatment price high. However, if the coefficient of patients' quality preference goes beyond a certain range, especially at a very high level, the treatment price will no longer be the priority in patients' consideration. To achieve effective treatment without waiting in a queue will be the first thing considered by the patients. In this situation, the treatment price will lose the ability to balance market supply and demand. Opposite to this, if the coefficient of patients' quality preference is low, the service quality competition among medical institutions will be ineffective. Patients are not sensitive to the quality of medical services. If they feel that the quality of medical services is the same, they will be sensitive to the price. The market share of which medical institution is cheap will be large. Therefore, medical institutions will adopt a low-price strategy.

The alliance as the price maker in the Stackelberg game determines a medical pricing strategy, medical institutions as the price taker have to respond to the strategy and make an optimal service quality strategy. The alliance has the first-mover advantage. When medical institutions are the price maker, the alliance as the price taker has to respond by determining an optimal medical pricing strategy. In this regard, medical institutions have the first-mover advantage.

To satisfy the needs of the initial solution for the bargaining model, the price level of unit quality for the equilibrium solutions (p_1, q_1) and (p_2, q_2) are standardized as $p_1^* = p_1/q_1$ and $p_2^* = p_2/q_2$.

The Bargaining Game for Co-payment Medical Expenses

A bargaining range (p_1^*, p_2^*) made by the medical institutions and the alliance is in a game. By applying the Rubinstein bargaining model, an equilibrium solution is achieved

$$\overline{p} = p_1^* + \frac{1-\theta 2}{1-\theta 1\theta 2}p_2^*$$

Where $\theta 1, \theta 2$ are the discount factors for the alliance and medical institutions, respectively. $\theta 1$ often depends on the patience level of the alliance in negotiation, the opportunity cost of medical treatment, and the severity of the diseases. $\theta 2$ depends on the patience level of medical institutions in negotiation, difficulty of patient referral, and the difficulty and risk of treatment.

Through the bargaining game between the alliance and medical institutions, the medical service is priced for the alliance as $\overline{p}$. In this second game, the government and patients will get in the game of sharing medical payments based on the price $\overline{p}$. The government and patients share the payment for the medical service through a third-party payment mechanism, i.e.,

health insurance. Paying through health insurance can easily put patients into moral hazard, because patients may be insensitive to medical prices and overspend on treatment. The early studies by Arrow (34) and Zeckhauser (35) find that health insurance should not fully cover all the medical cost. The effective payment method is to set a reasonable co-payment ratio, which diversifies the risks of patients and balances risks of patients' moral hazard and the profits of the insurance business. Ellis and Manning (36) and Eeckhoudt (37) state that the marginal profit achieved from the risk diversification by insurance equals their marginal cost in moral hazard; the health insurance co-payment ratio is the optima. Blomqvist (38) discusses the optimal design of health insurance co-payment ratio in a non-linear model and finds that the optimal health insurance co-payment ratio depends on patients' health level.

The medical pricing bargaining model was developed in the first stage by the alliance and medical institutions, which aims to prevent moral hazard caused by patient's excessive consumption of medical care. The medical treatment co-payment ratio game model developed in the second stage aims to prevent the overtreatment risk caused by the third-party payment system.

Based on the result in the first stage, by adding the co-payment ratio λ, the demand of medical function will be $D = a - b\lambda p$, which refers to a linear function of patients' medical demand, where $a \geq 0, b \geq 0$ and $0 \leq \lambda \leq 1$.

Patients' moral hazard in health insurance can cause waste in social welfare. Therefore, this study considers that the optimal co-payment rate is if and only if the social welfare loss caused by medical insurance is minimized. Three parts of health insurance may cause a loss in social welfare. The first part is the deadweight loss caused by patients' moral hazard. Based on Arrow's study, the deadweight loss caused by patients' moral hazard is $^{(1-\lambda)^2 b}/_{2}$. The second part is the government's expectation of opportunity cost on its medical support. This can be presented as $\delta\left[(1-\lambda)(a-b\lambda)\right]\bar{p}$. The third part is the cost of risk prevention, which is presented as $^{R\lambda^2\sigma^2}/_{2}$, where δ is the incidence of diseases, R is the coefficient of patients' absolute risk aversion, and σ^2 is the variance of the medical treatment price.

Therefore, the government's utility function is the total loss of social welfare.

$$\min WL = \frac{1}{2}(1-\lambda)^2 b + \delta[(1-\lambda)(a-b\lambda)]\bar{p} + \frac{1}{2}R\lambda^2\sigma^2 \quad (12)$$

By deriving (12), it will achieve

$$\frac{\partial WL}{\partial \lambda} = -(1-\lambda)b - b\delta\bar{p}(1-\lambda) - \delta\bar{p}(a-b\lambda) + R\lambda\sigma^2 = 0 \quad (13)$$

Solving (13) will achieve

$$\lambda^* = \frac{b + \delta\bar{p}(a+b)}{b + 2b\delta\bar{p} + R\sigma^2} \quad (14)$$

Lemma 3. *if and only if* $R \geq \frac{\sigma^2 b + \frac{1}{2}a\delta}{\delta^2 a}$, *the loss of total social welfare decreases, then increases with the increase of social health insurance co-payment ratio. If* $R < \frac{\sigma^2 b + \frac{1}{2}a\delta}{\delta^2 a}$, *the loss of total social welfare decreases with the increase of social health insurance co-payment ratio.*

The coefficient of patients' absolute risk aversion stands for the ability of patients to predict the incidence and loss caused by diseases. If the coefficient is lower than a certain threshold value, an increase in the social medical insurance co-payment ratio will bring about a reduction in the total social welfare loss, which is an increase in the total social welfare. In contrast, if the coefficient is higher than the certain threshold value, the increase of social health insurance co-payment ratio will reduce the loss of total social welfare first and then increase, which means that the total social welfare first increases and then decreases.

RESULTS AND DISCUSSION

The above section presents the bargaining game model on pricing and government compensation between the government, patients, and medical institutions. In the first stage, the alliance formed by the government and patients leads the price as the price maker. The alliance will determine a pricing strategy bases on social welfare maximization. Medical institutions as price takers will make a service quality strategy in response to the pricing strategy from the alliance. This will form a Stackelberg equilibrium solution between prices of disease treatment and medical service quality.

In the second stage, medical institutions will be the price maker in the game. Based on profit maximization, medical institutions will create an optimal service strategy for providing the highest level of medical quality. While based on the social welfare maximization, the alliance will be the price taker, to make an optimal disease treatment price in response to the optimal service strategy made by the medical institutions. This will create another Stackelberg equilibrium solution between prices of disease treatment and medical service quality.

Taking these two equilibrium solutions as the initial solution for the bargaining game between the alliance and medical institutions, and based on the bargaining power of the alliance and medical institutions, we can achieve an equilibrium price of Rubenstein's bargaining game through developing Rubenstein's game. In the final stage, based on the minimization of deadweight social loss, the government and patients will share the payment of medical costs. To analyze PED on diseases, the coefficient of patients' preferences on service quality, the coefficient of patients' absolute risk aversion, and the relationship between disease pricing and government compensation, this study provides several specific values to simulate a series of impacts on the equilibrium price. Firstly, the study analyzes the PED on the equilibrium price. It assumes that the coefficient of the demand function $a = 0.3$, the coefficient of disease treatment quality cost $\gamma = 10$, and the coefficient of patients' preferences on treatment quality $c = 0.6$. **Figure 1** shows the relationship between the equilibrium price and disease PED.

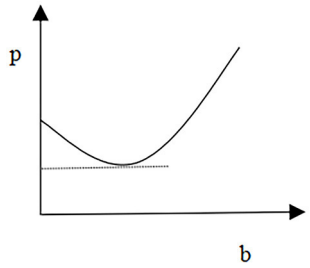


FIGURE 1 | Price and PED.

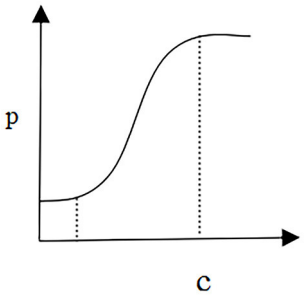


FIGURE 2 | Price and preference.

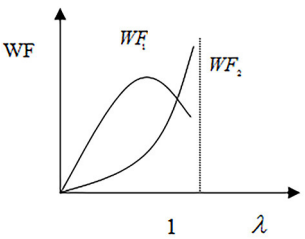


FIGURE 3 | Welfare and co-payment ratio.

The relationship presented in **Figure 1** is in a scenario where the optimal pricing strategy made by the alliance as a price maker will call for medical institutions to respond with their service quality strategy. It is a positive correlation between the treatment equilibrium price and disease treatment PED, i.e., the higher the PED in the treatment of the disease, the higher the price of the treatment. This is the opposite of Ramsey pricing. Medical services can be categorized as basic medical services and special medical services. The PED of basic medical services is low, and it is largely for non-profit-making purposes. In this regard, the pricing for this type of medication will be low. While special medical services have more significant commodity attributes and their high PED value leads the pricing to be higher than that of basic medical services.

To analyze the relationship between the treatment pricing and the coefficient of patients' service quality preference, it is necessary to set the elasticity of treatment demand $b = 0.3$, the parameter o'f the demand function $a = 0.3$, and the coefficient of treatment quality cost $\gamma = 10$.

Figure 2 shows a scenario that reflects the relationship between the equilibrium price of diseases and the coefficient of patients' quality preferences. In this scenario, medical institutions act as price makers. Based on the objective of maximizing profit, their priority is to optimize disease quality control decisions. Furthermore, the alliance of government and patients as the price taker will make the optimal price decision according to the goal of maximizing social welfare. In this model, when the coefficient of patients' quality preferences can be controlled in a certain range, the relationship between disease equilibrium price and patients' quality preference can be positive, i.e., the higher the coefficient of patients' quality preference, the more disease equilibrium price increases, and vice versa.

The curve WF_1 in **Figure 3** shows that the total social welfare increases first and then decreases with the increase of social medical insurance co-payment ratio, where the patients' absolute risk aversion coefficient is $R \geq \frac{\sigma^2 b + \frac{1}{2} a\delta}{\delta^2 a}$. The curve WF_2 presents another scenario in which the patients' absolute risk aversion coefficient is $R < \frac{\sigma^2 b + \frac{1}{2} a\delta}{\delta^2 a}$ and the total social welfare increases with the increase of social insurance co-payment ratio.

The above scenarios reflect the patient's risk aversion attitude toward health threats. When patients have a higher absolute risk aversion coefficient, they will experience more medical moral hazard, and when the co-payment rate of social insurance increases to a certain extent, it will lead to a loss on total social welfare. Opposite to this, when patients' absolute risk aversion coefficient reduces, their medical moral hazard decreases. This can lead to a continuous increase in the total social welfare while the social insurance co-payment ratio increases.

CONCLUSION

In the process of DRGs operation in many countries, especially in developing countries, such as India and China, unreasonable pricing and government compensation of medical services under the DRGs operation environment will lead to two major problems. On the one hand, underpricing will lead to medical institutions shirking the responsibility of critically ill patients and decomposing the DRGs category; on the other hand, overpricing will lead to a sharp increase in or even out of control medical expenses. To balance the interests of the government, patients, and medical institutions, the improved bargaining game model based on the Stackelberg game is introduced in order to balance this system and improve the total utility level of society.

The game pricing model developed in this study considers the relationship among the three roles including the government, medical institutions, and patients. The interests and behaviors of these roles have been studied through the models which present a suggestion on price negotiation and setting to the government and medical institutions, and the conducted result can guide medical institutions with a better price-setting strategy.

The model also classifies price-setting according to the price elasticity of demand for medical services. To be more realistic, the study has considered price-setting under the impact of patients' preferences for medical service quality. As a result, we find that the absolute risk aversion coefficient of patients affects the relationship between the co-payment rate of medical expenses and total social welfare. In addition, with more investment in public health education, the government can control the moral risk of over-treatment of patients during the operation of DRGs by influencing the absolute risk aversion coefficient of patients and limiting the absolute risk aversion coefficient of patients in a certain range. The future of this study is to generalize these models to DRGs pricing systems with the effects of competition of medical institutions, including considering differences in the compensation of DRGs systems between infirmaries and hospitals, in order to promote the goal of hierarchical diagnosis and treatment.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

JD conceiving the algorithm, designing the model, and writing—original draft. ZL revising and editing. FJ writing and editing. All authors contributed to the article and approved the submitted version.

FUNDING

This work was partially supported by the Innovation Strategy Research Project of Fujian Province under grant 2020R0090.

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frontiers in Public Health

ORIGINAL RESEARCH
published: 07 February 2022
doi: 10.3389/fpubh.2022.738146

Universal Health Insurance Coverage and the Economic Burden of Disease in Eastern China: A Pooled Cross-Sectional Analysis From the National Health Service Survey in Jiangsu Province

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OPEN ACCESS

Edited by:
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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: 08 July 2021
Accepted: 06 January 2022
Published: 07 February 2022

Citation:
Zhou S, Zhou C, Yuan Q and Wang Z (2022) Universal Health Insurance Coverage and the Economic Burden of Disease in Eastern China: A Pooled Cross-Sectional Analysis From the National Health Service Survey in Jiangsu Province. Front. Public Health 10:738146. doi: 10.3389/fpubh.2022.738146

China has achieved universal social health insurance coverage, but it is unclear whether this has alleviated the economic burden of disease for individuals. This was investigated in the present study by analyzing National Health Service Survey (2008–2018) data from Jiangsu province. Ordinary least squares and binary multivariate logistic regression of pooled cross-sectional data were carried out to evaluate the effect of universal health insurance coverage and other socioeconomic factors on the economic burden of disease. Total health expenses (THE) first increased and then decreased during the survey period while out-of-pocket health expenses (OOP) decreased except for urban residents, for whom OOP increased after 2013. Household catastrophic health expenditure (HCHE) was stable between 2008 and 2013 but increased after 2013. Social health insurance had a significant positive effect on the annual THE and OOP and a negative effect on HCHE, however, universal health insurance coverage could alleviated THE and the economic burden of disease on individuals (OOP) while it was insufficient to protect against the economic risk of diseases (HCHE), with greater benefits for urban as compared to rural residents. Other socioeconomic factors including age, marital status, education, income, and health status also influenced the economic burden of disease.

Keywords: universal health insurance coverage, economic burden of disease, total health expense (THE), out-of-pocket health expense (OOP), household catastrophic health expenditure (HCHE)

INTRODUCTION

In 2013, the World Health Organization (WHO) put forth the concept of universal health coverage, which aims to ensure that all people can access good quality health services without falling into poverty (1). Medical expenses can directly affect the economic burden of disease on individuals, which can adversely impact their health status. The economic burden of disease refers to economic losses to patients, families, or society caused by disease, disability, and premature death (2). Countries all over the world have taken various measures to alleviate this burden such as medical

insurance, which is an economic risk-sharing strategy (3) that is popular because it promotes mutual aid while reducing individual burden (4). Social health insurance systems covering the whole population have become the basis for ensuring a certain standard of national health (5).

Since the Decision on Establishing the Basic Medical Insurance System for Urban Workers in 1998, China's social health insurance system has made great progress in terms of coverage rate, which increased from 21% in 2003 (6) to more than 95% in 2020 (7). The current health insurance system framework in China consists of Urban Employees' Medical Insurance, Urban Residents' Medical Insurance (URMI), and New Rural Cooperative Medical Scheme (NCMS). In January 2016, the General Office of the State Council issued the Opinions on Integrating the Basic Medical Insurance System for Urban and Rural Residents, which proposed merging URMI and NCMS into Urban and Rural Residents' Medical Insurance.

Health insurance has been shown to reduce the economic burden of disease (8–11). In general, medical insurance can promote health and economic security (12). A study conducted in India found that community-based medical insurance reduced household catastrophic health expenditure (HCHE) (13). Health insurance involves risk-sharing, which can lower the cost of medical services and thus reduce the economic burden on patients (8). However, it has also been argued that this effect is limited and that health insurance can actually increase patients' medical expenditure (economic burden) (14–17). For example, Sepehri et al. found that insurance had no significant impact on decreasing out-of-pocket spending (18). And an analysis of the medical insurance systems in Philippines also showed that it did not significantly alleviate the economic risks of disease (19).

Even with the continuous improvement of the social health insurance system, health expenditures and the economic burden of disease are increasing for the Chinese population (20). Studies on the effect of social health insurance on the economic burden of disease in China have yielded conflicting findings. One study found that health insurance reduced the cost of health services for individuals through the sharing of health expenses (9). The NCMS (21) and URMI (22) were shown to significantly reduce the medical expenses of rural residents and alleviated the medical economic burden of rural and urban residents, respectively. However, others have demonstrated that the NCMS did not decrease the actual economic burden and incidence of critical disease (23). Although social health insurance increased health service utilization among the elderly, there was no corresponding reduction in the economic burden of disease (24). It was also determined that social health insurance increased the cost of medical services, thus increasing the economic burden on patients (14, 25). Clarifying the effect of social health insurance on the economic burden of disease is important as this can affect the choice of medical treatment and individuals' health status as well as socioeconomic development as a whole in China (19).

Most studies to date on the effect of social health insurance on the economic burden of disease have always analyzed cross-sectional data or examined specific populations or insurance types (2), however, with the adjustment and change of policies, the role of health insurance will also change. Therefore, our findings may conduct a comprehensive evaluation of the policy effect in the process of universal health insurance coverage based on the whole population. In this context, we used the data from the National Health Service Surveys (NHSS) conducted in Jiangsu province from 2008 to 2018, which spans the period of China's medical reform and the introduction of universal social health insurance coverage to investigate the effect of universal social health insurance on Chinese residents' economic burden of disease based on. Specifically, we first evaluated trends in the economic burden of disease between 2008 and 2018, then estimated the associations between universal social health insurance coverage, socioeconomic factors, and the economic burden of disease by regression analysis of pooled cross-sectional data. Our results can guide government initiatives to reduce the economic burden of disease for the population but especially for vulnerable groups, and provide a reference for establishing universal medical insurance systems in other developing countries.

MATERIALS AND METHODS

Data Source

Data were obtained from the 4th (2008), 5th (2013), and 6th (2018) NHSSs. The survey is conducted every 5 years by the Center for Health Statistics and Information of the National Health Commission. The survey sites were selected by multistage stratified random sampling and included 156 counties (cities and districts) in 31 provinces. Five towns (streets) were randomly selected in each county, two villages (neighborhood committees) were randomly selected in each town, and 60 households were randomly selected in each village for a total survey population of nearly 300,000 from 93,600 households nationwide. Jiangsu is a densely populated province in Eastern China with a population of 80.293 million, and is one of the most developed provinces in the country. Our group organized and completed the NHSS in Jiangsu province. A total of 19 counties were surveyed; from these, 7021, 10,466, and 11,550 individuals were randomly selected in 2008, 2013, and 2018, respectively, and included in our analysis. Excluding the missing data, the whole sample included 25,042 respondents over the age of 15 years.

The data in the NHSS covered detailed personal information including demographic and socioeconomic characteristics of urban and rural residents (sex, marital status, education level, household size, employment status, income level, health insurance, self-reported health status, and chronic diseases, etc). The survey also included questions on respondents' health service utilization and medical expenses.

Variable Selection

In most studies, the economic burden of disease on individuals is defined as medical expenses (26, 27) or the proportion of household health expenditure in household disposable income (8, 28). Considering the questionnaire content and our research objectives, we selected three dependent variables as indicators of the economic burden of disease on respondents—namely, annual total health expenses (THE), annual out-of-pocket medical expenses (OOP), and HCHE. The main

TABLE 1 | Description of variables.

	Category	Indicator/survey question
Dependent variable		
Total health expenditure		Sum of outpatient and inpatient expenses in the past year
Out-of-pocket health expenditure		Sum of out-of-pocket outpatient and inpatient expenses in the past year
Household catastrophic health expenditure	0, No 1, Yes	
Independent variable		
Predisposing factors		
Sex	1, Male 2, Female	Question: What is your sex?
Age (years)	1, ≤30 2, 30–45 3, 45–60 4, >60	Question: What is your year of birth?
Household number	1, ≤2 2, >2	Question: What is the size of your household?
Marital status	1, Unmarried 2, Married	Question: What is your marital status? (Widowhood and divorced both belong to "Not married")
Education level	1, Less than secondary 2, Upper secondary/ vocational training 3, Tertiary	Question: What is your education level?
Employment status	0, Unemployed 1, Employed 2, Retired	Question: What is your employment status?
Enabling factor		
Social health insurance	0, No 1, Yes	Question: Do you have any social health insurance?
Financial subsidies	0, No 1, Yes	Question: Are you a Medicaid recipient or living in a poor or low-income household?
Income level	1, Lowest 2, Lower 3, Higher 4, Highest	Yearly household income divided by the number of household members; the first household member is assigned a weight of 1, with all other members assigned a weight of 0.5
Area of residence	0, Rural 1, Urban	Question: What is your registered residence type?
Need factor		
Depression	0, Not depressed 1, Depressed	Question: What is the extent of your depression?(The answer is "not depressed," "mildly depressed," "moderately depressed" and "severely depressed," and the last three were considered depressed.)
Self-reported health status (VAS score)	1, ≤49 2, 49–70 3, 70–80 4, 80–100	Question: How would you rate your health today on a scale of 0 (worst possible health) to 100 (best possible health)?
Smoking	0, No 1, Yes	Question: Have you ever been or are you currently a smoker?
Drinking	0, No 1, Yes	Question: Do you currently drink alcohol?
Chronic diseases	0, No chronic disease 1, 1 Chronic disease 2, >1 Chronic diseases	Questions: Do you have confirmed hypertension or diabetes? Have you been diagnosed with other chronic diseases?

VAS, Visual Analog Scale.

explanatory variables including health insurance and other socioeconomic variables were selected based on Anderson's healthcare utilization behavior model (29–31). There were predisposing variables (demographic characteristics such as age, sex, etc), enabling variables (socioeconomic characteristics such as medical insurance, income, education level, etc), and need variables (indicators related to individual health status such as self-reported health status, chronic diseases, etc). Given that the data were pooled and cross-sectional, we also examined the effect of time and the interaction effect of time and social health insurance. Detailed descriptions of the variables can be found in (**Table 1**).

Statistical Analysis

Descriptive Analysis

Data were analyzed using SPSS v25.0 (SPSS Inc, Chicago, IL, USA) and Stata v13.0 (College Station, TX, USA). The significance of differences between groups was evaluated with the Pearson chi-squared test and analysis of variance. All cost data were converted to the value in 2008.

Calculation of the Economic Burden of Disease

Indicators of the economic burden of disease included annual THE, annual OOP, and incidence of HCHE; these were calculated with the Equations 1–3 below.

$$THE = 26 * \sum_{k=1}^{n} (A_k + B_k) + \sum_{k=1}^{m} (C_k) \quad (1)$$

$$OOP = 26 * \sum_{k=1}^{n} (a_k + b_k) + \sum_{k=1}^{m} (c_k) \quad (2)$$

$$HCHE_i = \begin{cases} 0 \; if \, T_i/(x_i - f(x) < z \\ 1 \; if \, T_i/(x_i - f(x) \geq z \end{cases} \quad (3)$$

In equation (1), A_k is the average cost per visit to hospital or a doctor in 2 weeks, B_k is the average cost of drug purchases within a 2-week period, n is the number of visits to hospital or a doctor in a 2-week period, C_k is the average cost of hospitalization in 1 year, and m is the average hospitalization time in 1 year. In Equation 2, a_k is the average out-of-pocket health expenses per visit to hospital or a doctor in 2 weeks, b_k is the average out-of-pocket

TABLE 2 | Characteristics of the study population according to area of residence (urban vs. rural).

	Total	Urban	Rural	*p*
	25,042	10,931 (43.65)	14,111 (56.35)	
Year				<0.001
2008	23.96	12.73	32.66	
2013	37.07	43.04	32.44	
2018	38.97	44.22	34.89	
Predisposing factor				
Sex				0.024
Male	48.93	48.12	49.56	
Female	51.07	51.88	50.44	
Age in years				<0.001
≤30	17.04	17.17	16.94	
30–45	22.76	21.08	24.07	
45–60	30.94	27.66	33.48	
>60	29.25	34.09	25.51	
Number of household members				<0.001
≤2	30.49	33.36	28.26	
>2	69.51	66.64	71.74	
Marital status				<0.001
Not married	17.78	18.82	16.97	
Married	82.22	81.18	83.03	
Education level				<0.001
Less than lower secondary	33.32	20.85	42.99	
Upper secondary/vocational training	53.28	55.96	51.20	
Tertiary	13.40	23.19	5.81	
Employment status				<0.001
Not employed	17.99	17.77	18.16	
Employed	66.26	49.46	79.27	
Retired	15.75	32.77	2.57	
Enabling factor				
Income				<0.001
Lowest income	25.01	9.01	37.40	
Lower income	25.55	20.57	29.40	
Higher income	25.00	31.71	19.80	
Highest income	24.45	38.71	13.40	
Social health insurance				0.008
No	3.50	3.85	3.23	
Yes	96.50	96.15	96.77	
Social health insurance type				<0.001
None	3.50	3.85	3.23	
UEMI	35.12	68.01	9.65	
URMI	11.28	23.68	1.68	
NCMS	28.55	2.47	48.76	
Other	21.54	1.99	36.68	
Financial subsidies				<0.001
No	96.24	97.15	95.54	
Yes	3.76	2.85	4.46	
Need factors				
Depression				<0.001
Not depressed	94.90	96.52	93.65	
Depressed	5.10	3.48	6.35	
Self-reported health status				<0.001
Poor (<50)	1.44	1.17	1.64	
Fair (50–70)	21.68	22.14	21.32	
Good (70–80)	27.53	30.14	25.51	
Excellent (80–100)	49.35	46.55	51.52	
Smoking				0.006
No	75.76	76.61	75.10	
Yes	24.24	23.39	24.90	
Drinking				0.005
No	76.77	77.61	76.11	
Yes	23.23	22.39	23.89	
Chronic diseases				<0.001
0	68.64	63.13	72.90	
1	22.54	25.86	19.97	
≥2	8.82	11.01	7.13	

All data are shown as n (%) or %.

NCMS, New Rural Cooperative Medical Scheme; UEMI, Urban Employees' Medical Insurance; URMI, Urban Residents' Medical Insurance.

Lowest income, ≤¥11073.24; Lower income: ¥11073.24–20994.01; Higher income, ¥20994.01–34990.02; Highest income, >¥34990.02.

health expenses for medicines purchased over a 2-week period, n is the number of visits to hospital or a doctor in a 2-week period, c_k is the average out-of-pocket expenses for hospitalizations in 1 year, and m is the average hospitalization time in 1 year. In Equation 3, $HCHE_i$ is HCHE in a given household i, T_i is annual total health expenditure of the household, x_i is the annual consumption expenditure of the household, $f(x)$ is the annual food consumption expenditure of the household, and z is the threshold of 40% recommended by the WHO (32–34).

Regression Analysis

Ordinary least square and binary multivariate logistic regression analyses of pooled cross-sectional data were carried out to evaluate the effects of health insurance and other factors on residents' THE, OOP, and HCHE. Variables for time and the interaction of time and social health insurance were also introduced to assess the impact of the universal health insurance system in China on residents' economic burden of disease.

RESULTS

Characteristics of the Study Population

There were 25,042 survey participants from Jiangsu province including 10,931 urban residents (43.65%) and 14,111 rural residents (56.35%); 23.96% were from 2008, 37.07% were from 2013, and 38.97% were from 2018. The ratio of males to females was close to 1:1 (male:48.93, female:51.07%), and more than two-thirds of residents lived in a household of ≥2 members.

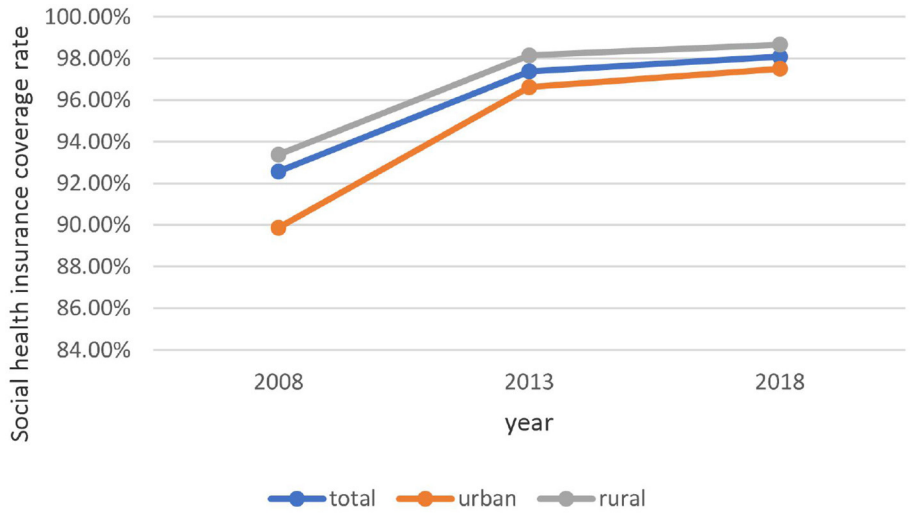


FIGURE 1 | Trends in social health insurance coverage rate among residents of urban and rural areas from 2008 to 2018.

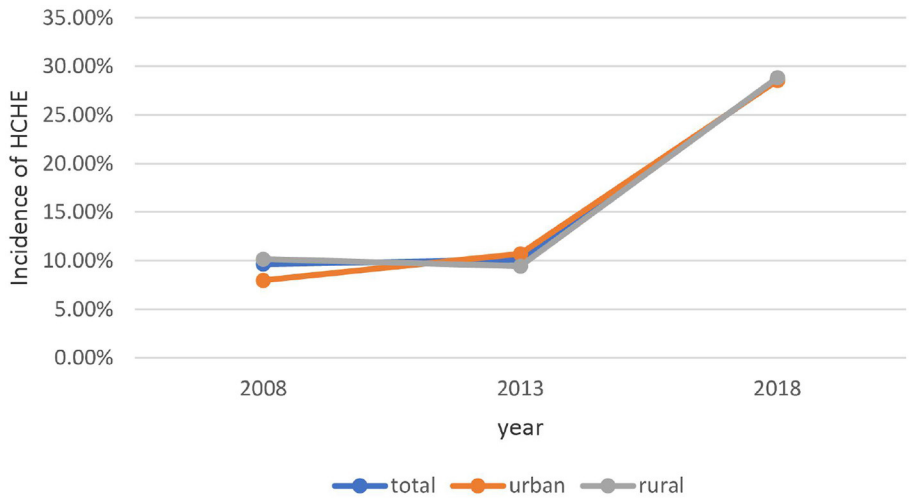


FIGURE 2 | Trends in HCHE incidence among residents of urban and rural areas from 2008 to 2018.

The proportion of urban residents who had a higher education level was 76.81% which was larger than that of rural residents, while the latter had a higher proportion of individuals with the lowest education level (42.99%). The rates of employment in urban and rural areas were 49.46 and 79.27%, respectively, and there was a higher proportion of retirees in urban areas (32.77 vs. 2.57% in rural areas). Social health insurance coverage rate was >96% in both urban and rural areas. Details of other characteristics including depression, self-reported health status, chronic diseases, etc are shown in (**Table 2**).

Social Health Insurance Coverage Rate and Economic Burden of Disease

Social health insurance coverage rate showed an increasing trend from 2008 to 2018 in the total population (2008: 92.57; 2013: 97.37; 2018: 98.08%) and among urban residents (2008: 89.87; 2013: 96.62; 2018: 97.50%) and rural residents (2008: 93.38; 2013: 98.14; 2018: 98.66%) (**Figure 1**). The incidence of HCHE was relatively stable from 2008 to 2013, and increased sharply from 2013 to 2018 in the total population (2013: 10.08; 2018: 28.67%) and in urban (2013: 10.71; 2018: 28.53%) and rural (2013: 9.44; 2018: 28.82%) areas (**Figure 2**). Annual THE showed an increasing trend before declining (2008: ¥4000; 2013: ¥4548.70; 2018: ¥3290.34) (**Figure 3**). THE was lower for rural residents (2008: ¥3900; 2013: ¥4373.75; 2018: ¥2534.19) than for urban residents (2008: ¥5000; 2013: ¥5248.50; 2018: ¥4112.92), and the degree of decline of THE between 2013 and 2018 was greater for the former. Annual OOP showed a downward trend for the total population (2008: ¥3000; 2013: ¥2186.88; 2018: ¥2056.46) and for rural residents (2008: ¥3235;

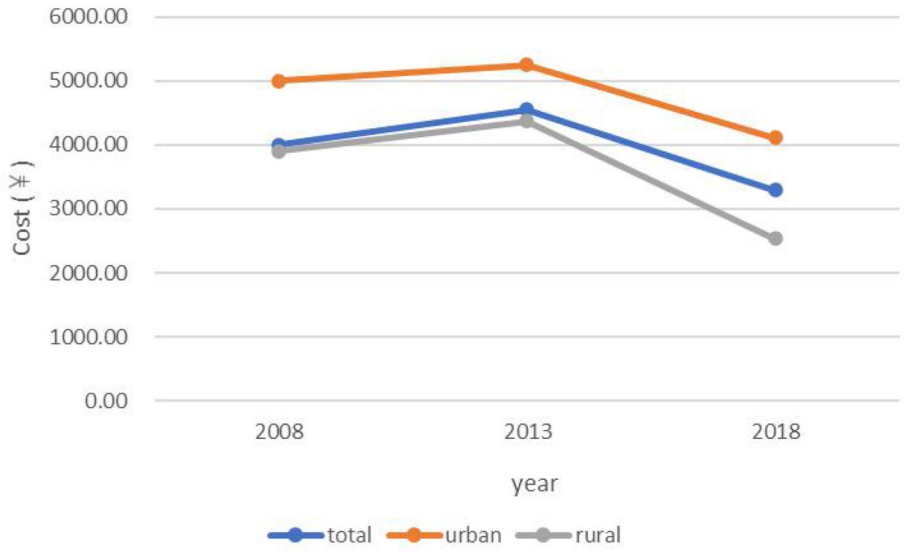


FIGURE 3 | Trends in annual THE among residents of urban and rural areas from 2008 to 2018.

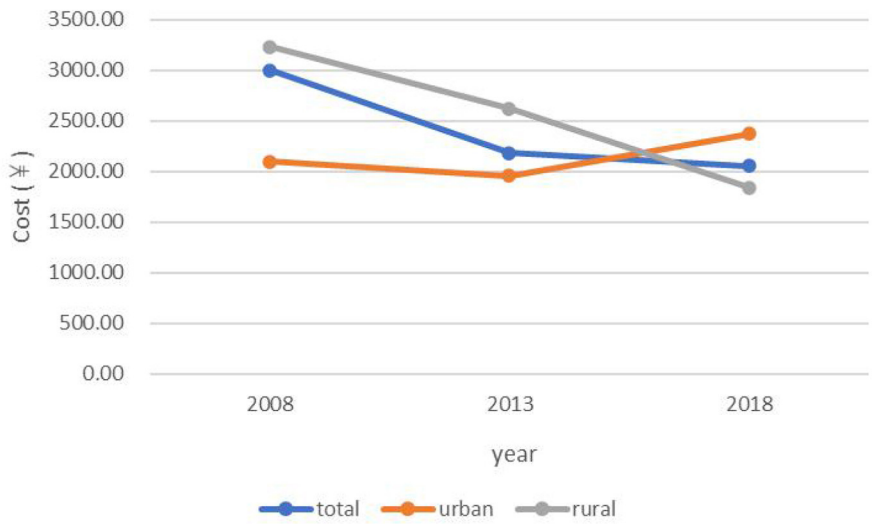


FIGURE 4 | Trends in annual OOP among residents of urban and rural areas from 2008 to 2018.

2013: ¥2624.25; 2018: ¥1840.53) but among urban residents, OOP initially decreased and then increased (2008: ¥2100; 2013: ¥1955.94; 2018: ¥2372.84) (**Figure 4**). Furthermore, OOP was lower for urban residents in 2008 and 2013 and higher in 2018 than for rural residents in those years.

Multivariate Regression Analysis

Regression Analysis of THE

THE was significantly higher for insured residents than for uninsured residents in the total population (coef = 5.889) and in urban (coef = 7.325) and rural (coef = 5.190) areas (**Table 3**). THE was significantly higher in 2013 than in 2008 (total: coef = 5.852; urban: coef = 7.176; rural: coef = 5.468) but was significantly lower in 2018 (total: coef = −5.722; urban: coef = −7.330; rural: coef = −4.895). The coefficient of interaction of time (year) and social health insurance was significantly negative, and the absolute value of the coefficient was greater than that with health insurance in the total population (2013 × insurance: coef = −6.016; 2018 × insurance: coef = −6.247) and among urban (2013 × insurance: coef = −7.284; 2018 ×insurance: coef = −7.644) and rural (2013 × insurance: coef = −5.578; 2018 × insurance: coef = −5.529) residents. The absolute values of the coefficients of the three variables were greater in the urban population than in the rural population.

TABLE 3 | Regression analysis of annual total health expenditure (log) of urban and rural residents.

	Total		Urban		Rural	
	coef	**SE**	**coef**	**SE**	**coef**	**SE**
Predisposing factor						
Sex, ref: male	0.008	0.064	−0.104	0.091	0.084	0.089
Age (years), ref: ≤30						
30–45	0.556***	0.107	0.240	0.149	0.809***	0.152
45–60	0.444***	0.109	0.288	0.162	0.671***	0.151
>60	0.630***	0.117	0.367*	0.175	0.891***	0.161
Number of household members, ref: ≤2	0.237***	0.055	0.124	0.079	0.306***	0.076
Marital status, ref: not married	0.618***	0.074	0.365***	0.103	0.792***	0.105
Education level, ref: less than secondary						
Upper secondary	0.348***	0.063	0.114	0.091	0.558***	0.086
Tertiary	0.608***	0.117	0.317*	0.143	0.943***	0.207
Employment status, ref: unemployed						
Employed	−0.029	0.071	−0.117	0.116	−0.054	0.093
Retired	−0.105	0.088	−0.119	0.108	0.197	0.186
Enabling factor						
Income, ref: <¥11,663						
¥11,663–21,869	0.178*	0.074	0.281*	0.141	0.168	0.091
¥21,869–36,911	0.213**	0.079	0.470**	0.139	0.089	0.104
>¥36,911	0.210*	0.086	0.363*	0.142	0.209	0.120
Social health insurance, ref: not insured	5.889***	0.175	7.325***	0.305	5.190***	0.222
Area of residence, ref: rural	0.414***	0.064				
Financial subsidies: ref: not receiving subsidies	0.233*	0.114	0.194	0.203	0.310*	0.140
Need factor						
Depression, ref: not depressed	0.599***	0.083	0.192	0.140	0.754***	0.104
Self-reported health status, ref: poor						
Fair	1.053***	0.126	0.693***	0.194	1.156***	0.166
Good	0.719***	0.133	0.319	0.200	0.860***	0.179
Excellent	0.783***	0.136	0.444*	0.205	0.882***	0.182
Smoking, ref: no smoking	−0.271***	0.075	−0.262*	0.113	−0.287**	0.099
Drinking, ref: no drinking	−0.219**	0.071	−0.202	0.105	−0.232*	0.096
Chronic diseases, ref: 0						
1	0.198**	0.064	−0.143	0.100	0.416***	0.084
≥2	0.538***	0.077	0.273*	0.113	0.677***	0.106
Year, ref: 2008						
2013	5.852***	0.376	7.176***	0.464	5.468***	0.652
2018	−5.722***	0.295	−7.330***	0.395	−4.893***	0.464
Interaction of year and health insurance						
YI2013	−6.016***	0.381	−7.284***	0.485	−5.578***	0.658
YI2018	−6.247***	0.300	−7.644***	0.414	−5.529***	0.469

*$p<0.05$, **$p<0.01$, ***$p<0.001$.
ref, reference; SD, standard deviation.

THE of older residents was significantly higher than that of younger residents in the total population (30–45 years: coef = 0.556; 45–60 years; coef = 0.444; >60 years: coef = 0.630); however, in the urban population, only respondents over the age of 60 years had a higher THE. In the total population and among rural residents, THE was significantly higher in larger households (total: coef = 0.237; rural: coef = 0.306) and in respondents with a higher (upper secondary or tertiary) education level (total: coef = 0.348 and 0.608, respectively; rural: coef = 0.558 and 0.943, respectively) than in smaller households and respondents with a low education level. Compared to those who were unmarried, married respondents had a higher THE (total: coef = 0.618; urban: coef = 0.365; rural: coef = 0.792). THE was higher among urban residents than among residents of rural areas

TABLE 4 | Regression of annual out-of pocket health expenditure of residents.

	Total OOP (take the logarithm)		Urban OOP (take the logarithm)		Rural OOP (take the logarithm)	
	coef	**SE**	**coef**	**SE**	**coef**	**SE**
Predisposing factors						
Sex, ref:male	−0.240***	0.062	−0.212*	0.087	−0.254**	0.089
Age, ref:≤30						
30–45	0.118	0.105	0.026	0.139	0.181	0.158
45–60	−0.202	0.108	0.018	0.152	−0.272	0.158
>60	−0.262*	0.117	−0.121	0.165	−0.276	0.169
Household numbers, ref:≤2	0.126*	0.053	0.078	0.075	0.165*	0.075
Marital status, ref:not married	0.377***	0.072	0.205*	0.098	0.539***	0.105
Education level, ref:less than secondary						
Upper secondary	0.078	0.061	0.010	0.087	0.146	0.085
Tertiary	−0.033	0.111	−0.026	0.136	0.070	0.199
Employment status, ref:unemployed						
Employed	−0.148*	0.067	−0.181	0.108	−0.135	0.090
Retired	−0.121	0.082	−0.181	0.101	−0.044	0.181
Enalbing factors						
Income, ref:≤￥11663						
￥11663∼21869	0.050	0.070	0.152	0.124	0.074	0.089
￥21869∼36911	0.115	0.074	0.277*	0.123	0.054	0.098
>￥36911	0.124	0.080	0.188	0.127	0.200	0.114
Social health insurance, ref:not insured	8.075***	0.212	8.024***	0.326	8.090***	0.288
Area of residence, ref:rural	−0.227***	0.059				
Financial subsidies:ref:not receiving financial subsidies	−0.129	0.110	−0.094	0.192	−0.071	0.136
Need factors						
Depression, ref:not depressed	0.276**	0.080	0.047	0.132	0.389***	0.103
Self-reported health status, ref:poor						
Fair	−0.007	0.126	0.040	0.192	−0.062	0.168
Good	−0.436**	0.134	−0.387	0.199	−0.513**	0.182
Excellent	−0.441**	0.138	−0.330	0.204	−0.554**	0.187
Smoking,ref:no smoking	−0.259	0.072	−0.218*	0.108	−0.340***	0.097
Drinking,ref:no drinking	−0.241	0.067	−0.187	0.099	−0.260**	0.091
Chronic diseases, ref:0						
1	0.110	0.062	0.019	0.095	0.188*	0.083
≥2	0.383	0.073	0.301**	0.106	0.436***	0.101
Year, ref:2008						
2013	−8.172	0.352	−8.343***	0.438	−8.210***	0.605
2018	−7.924	0.288	8.284***	0.379	−7.686***	0.457
Interaction of year and health insurance						
YI2013	−8.378***	0.368	−8.452***	0.472	−8.410***	0.622
YI2018	−8.236***	0.305	−8.206***	0.414	−8.243***	0.477

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
ref, reference; SD, standard deviation.

(coef = 0.414) and was higher among respondents who were receiving financial subsidies from the government (coef = 0.233). Respondents with depression (coef = 0.599); 1 or ≥2 chronic diseases (coef = 0.198 and 0.538, respectively); and fair, good, or excellent self-reported health status (coef = 1.053, 0.719, and 0.783, respectively) had significantly higher THE than those without depression or chronic diseases or who had poor self-rated health. Respondents who were smokers (coef = −0.271) or drank alcohol (coef = −0.219) had significantly lower THE than those who did not engage in these activities.

Regression Analysis of OOP

Social health insurance was associated with a significantly higher annual OOP (total: coef = 8.075; urban: coef = 8.024; rural: coef = 8.090) (**Table 4**). Among rural residents, OOP was significantly lower in 2013 and 2018 than in 2008 (2013: coef = −8.210; 2018: coef = −7.686), whereas among urban residents OOP was significantly higher in 2018 than in 2008 (2013: coef = −8.343; 2018: coef = 8.284). The coefficient of interaction of year and health insurance was significantly negative, and the absolute value was slightly higher than that with social health insurance.

Respondents over the age of 60 years and those who were employed had significantly lower OOP than those younger than 30 years of age or who were unemployed (age >60 years: coef = −0.262; employed: coef = −0.148). Respondents who were male, from a large household (>2), or who were married had a higher OOP than those who were female (coef = −0.240), from a small household (coef = 0.126), or who were unmarried (coef = 0.377). OOP was higher among urban residents in the second-highest income bracket than among those with the lowest income (coef 0.277), and was higher in rural residents and in the total population with depression than in respondents in these groups without depression (total: coef = 0.276; rural: coef =0.389). Respondents who reported their health status as "good" or "excellent," were smokers, or who drank alcohol had a lower annual OOP than those who had poor self-reported health and did not smoke or drink. Additionally, OOP was higher for respondents with chronic diseases (≥2) than for those without chronic diseases (urban: coef = 0.301; rural: coef = 0.436).

Logistic Regression Analysis of HCHE

The associations between social health insurance and other socioeconomic factors and HCHE are summarized in (**Table 5**). The probability of HCHE was significantly lower in households with insured residents (total: OR = 0.573; urban: OR = 0.597; rural: OR = 0.580). Compared to 2008, the probability of HCHE was increased in 2018 (total: OR = 3.118; urban: OR = 4.495; rural: OR = 2.614), and the OR of the interaction of the year 2018 and health insurance was significant in the total population (OR = 1.784), which was contrary to the effect of social health insurance on HCHE. By comparing the ORs of the two variables, we found that the positive interaction effect of the year 2018 and insurance on HCHE was greater than the negative effect of health insurance on HCHE.

The probability of HCHE was significantly lower in households with females (total: OR = 0.786; urban: OR = 0.772; rural: OR = 0.782) (**Table 5**). Households with residents aged 45–60 years also had a significantly lower probability of HCHE (OR = 0.685). Having fewer household members (≤2) was significantly and positively associated with HCHE compared to living in a household with more members (>2) (total: OR = 0.574; urban: OR = 0.688; rural: OR = 0.496). The probability of HCHE was higher for households in the total population and in urban areas with married respondents (total: OR = 1.190; urban: OR = 1.254), and lower for those with respondents with a high education level (total: OR = 0.910; rural: OR = 0.839). Furthermore, the probability of HCHE was lower for households in urban areas with employed respondents (OR = 0.825). All of the enabling and need factors had a significant impact on the probability of HCHE. Households in which respondents had a higher income or better health, smoke or drank alcohol had a significantly lower incidence of HCHE. Households in rural areas (OR = 0.344), receiving government financial assistance (OR = 1.781), or with respondents who experienced depression (OR = 1.291) or had 1 or ≥2 chronic diseases (OR = 1.355 and 1.782, respectively) had a significantly higher probability of HCHE.

DISCUSSION

China established a universal social health insurance system in 2003 to ensure the health of the population through shared economic risks of disease and improved accessibility of health services (35–37). However, whether universal social health insurance coverage has alleviated the economic burden of disease for individuals has not been systematically investigated. To this end, the present study analyzed the trends in residents' economic burden of disease (including THE, OOP, and HCHE) from 2008 to 2018 and how this was affected by universal social health insurance coverage and other socioeconomic factors using NHSS data from Jiangsu province.

TRENDS IN SOCIAL HEALTH INSURANCE COVERAGE RATE AND ECONOMIC BURDEN OF DISEASE

Social health insurance coverage has gradually increased in China; in 2018, the coverage rate in urban and rural areas exceeded 97%, which was close to full coverage for the population. Additionally, the health insurance coverage rate was consistently higher in rural areas than in urban areas, which may be related to differences in policy implementation.

Consistent with previous studies (38–40), THE was significantly higher for urban residents than for rural residents. This may be attributable to the higher degree of socioeconomic development and better medical resource allocation in urban areas that make health services more affordable and accessible, thereby increasing health service expenditure. Also in agreement with earlier findings (38, 41) was our observation that OOP was higher for rural residents than for urban residents, but only in the early part of the survey period; that is, the gap between the two groups decreased as social health insurance coverage became widespread. The incidence of HCHE was also higher among rural residents, which was likely due to their lower income level and limited medical security level (4). Therefore, the government should improve allocation of health resources between urban and rural areas and optimize health insurance systems in the latter by increasing financial support and income levels to reduce the economic burden and risks of disease.

From 2008 to 2018, THE increased before decreasing. The first part of this trend may be related to improvements in the medical system and health insurance coverage after the medical reforms of 2009, which increased utilization of health services and THE (42). During implementation of the reforms, the regulations of the medical insurance system (e.g., cancellation of drug bonuses) were continuously updated; this along with the decline of drug prices and moral hazard of social health insurance resulted in a decrease in THE. In the total population and among rural residents, OOP decreased from 2013 to 2018 whereas in urban areas it increased after 2013, exceeding the OOP of rural residents in 2018. The high THE among urban residents may have led to a higher OOP even after reimbursement. Establishing critical illness insurance can potentially reduce OOP in this group. The incidence of HCHE remained relatively stable between 2008

TABLE 5 | Logistic regression analysis of the likelihood of household catastrophic health expenditure of urban and rural residents.

	Total		Urban		Rural	
	OR	**SE**	**OR**	**SE**	**OR**	**SE**
Predisposing factor						
Sex, ref: male	0.786***	0.036	0.772***	0.052	0.782***	0.050
Age (years), ref: ≤30						
30–45	0.791**	0.057	0.857	0.089	0.750**	0.075
45–60	0.685***	0.051	0.709**	0.081	0.638***	0.066
>60	0.891	0.072	0.827	0.103	0.895	0.097
Number of household members, ref: ≤2	0.574***	0.023	0.688***	0.041	0.496***	0.028
Marital status, ref: not married	1.190**	0.064	1.254**	0.098	1.126	0.084
Education level, ref: less than secondary						
Upper secondary	0.910*	0.043	1.024	0.073	0.839**	0.055
Tertiary	0.868	0.070	0.839	0.088	1.085	0.145
Employment status, ref: unemployed						
Employed	0.909	0.048	0.825*	0.070	0.980	0.067
Retired	1.088	0.073	1.139	0.098	1.234	0.186
Enabling factor						
Income, ref: <¥11,663						
¥11,663–21,869	0.575***	0.030	0.598***	0.057	0.603***	0.039
¥21,869–36,911	0.385***	0.022	0.428***	0.040	0.347***	0.028
>¥36,911	0.227***	0.015	0.222***	0.022	0.270***	0.026
Social health insurance, ref: not insured	0.573***	0.066	0.597*	0.129	0.580***	0.083
Area of residence, ref: rural	0.344***	0.062				
Financial subsidies: ref: not receiving subsidies	1.781***	0.145	1.943***	0.275	1.712***	0.171
Need factor						
Depression, ref: not depressed	1.291***	0.093	1.016	0.132	1.432***	0.125
Self-reported health status, ref: poor						
Fair	0.618***	0.063	0.498***	0.085	0.739*	0.097
Good	0.403***	0.042	0.353***	0.061	0.448***	0.061
Excellent	0.310***	0.032	0.265***	0.046	0.360***	0.048
Smoking, ref: no smoking	0.884*	0.047	0.809**	0.066	0.924	0.065
Drinking, ref: no drinking	0.779***	0.040	0.799**	0.062	0.763***	0.054
Chronic diseases, ref: 0						
1	1.355***	0.064	1.242**	0.088	1.473***	0.094
≥2	1.782***	0.111	1.854***	0.163	1.699***	0.153
Year, ref: 2008						
2013	1.147	0.265	1.737	0.510	0.645	0.320
2018	3.188***	0.659	4.495***	1.256	2.614**	0.917
Interaction of year and health insurance						
YI2013	1.241	0.294	1.065	0.336	2.006	1.003
YI2018	1.784**	0.376	1.691	0.503	1.994	0.705

*$p<0.05$, **$p<0.01$, ***$p<0.001$.
ref, reference; SD, standard deviation.

and 2013 and then rose sharply from 2013 to 2018, which may be related to advances in medical technology, the aging of the population, and changes in disease burden.

EFFECT OF HEALTH INSURANCE AND UNIVERSAL COVERAGE ON THE ECONOMIC BURDEN OF DISEASE

Having health insurance increased residents' THE, which contradicts the findings of some previous surveys (9, 21, 43). This may be because social medical insurance has reduced the unmet demand for health services. Moral hazards of suppliers caused by information asymmetry in health services ["pushing up prices" (44), "inducing demand," or "overtreatment"] may have also contributed to the increase in THE (28). Hence, the government should strengthen the monitoring of health insurance funds and improve related regulations to promote the effective utilization of health services while reducing moral hazards in order to control THE (19). Although having social health insurance significantly increased THE in the population, universal social health insurance coverage had the opposite

effect. The coefficient of the interaction of health insurance and time was significantly negative and the absolute value was greater than that of the coefficient of social health insurance, implying that universal coverage and improvements in the health insurance system in China can mitigate the excessive increase in THE.

In accordance with published reports (3, 16, 19, 44), respondents in urban and rural areas with health insurance had significantly higher OOP than those without insurance. Social health insurance has eased the demand for health services, thereby promoting their utilization. Additionally, rapid economic development and changes in the disease spectrum have increased medical costs including OOP for residents. However, the positive effect of having medical insurance on OOP was diminished by universal social health insurance coverage, which was similar to Finkelstein & McKnight's finding and Nguyen H's report (45, 46), possibly because it has gradually improved the level of reimbursement. Thus, although having social health insurance increased OOP, the net effect of universal social health insurance coverage on OOP was slightly negative and alleviated to some extent the economic burden of disease.

The probability of HCHE was significantly lower among residents with health insurance, implying that having insurance protected residents from the economic risks of disease as demonstrated in other surveys (4, 5, 15, 16). However, with economic development and rising medical costs, the incidence of HCHE has increased significantly, as evidenced by a coefficient >1 for the interaction between the year 2018 and social health insurance. This indicates that although having health insurance reduced the probability of HCHE, this effect is gradually diminishing, such that the aggregate effect of universal of social health insurance coverage actually increased rather than decreased the probability of HCHE. That is, as the increase in medical costs has exceeded that of reimbursement, social health insurance is no longer sufficient to protect people from the economic risks of disease. To overcome this problem, the government should increase financial subsidies, modify medical insurance catalogs, and expand the scope of reimbursement for diseases (4). Additionally, a multilevel medical security system that includes medical assistance and critical illness insurance can potentially reduce the risk of HCHE.

OTHER SOCIOECONOMIC FACTORS ASSOCIATED WITH THE ECONOMIC BURDEN OF DISEASE

THE was significantly higher for respondents over the age of 60 years, which is consist with previous findings (47, 48). This may be because the elderly are more likely to suffer from diseases than younger people due to a decline in physical health. The effect was more pronounced in rural areas, possibly reflecting their inferior living conditions compared to urban residents. However, OOP was significantly lower for respondents older than 60 years than for those aged $\leq$30 years, which differs from the results of another study (49). This discrepancy may be attributable to special medical insurance policies for the elderly such as reimbursements for chronic or geriatric diseases.

As reported in earlier studies (48, 50, 51), respondents with higher education and income levels had a significantly higher THE but lower risk of HCHE. This may be because people with higher education and income are more likely to take the initiative to seek medical treatment in a timely manner and thereby prevent critical diseases and the associated economic burden. OOP and HCHE were higher among rural residents than in the urban population, highlighting the disparities in economic development and medical insurance policies between urban and rural areas. Additionally, OOP and incidence of HCHE were higher for respondents with poor self-reported health and chronic diseases (4, 52, 53) due to the greater demand for and utilization of health services by these individuals. Therefore, the government should pay more attention to vulnerable groups such as the elderly, rural residents, and people with a low level of education and chronic diseases (4) to avoid "poverty due to illness" in China. As for the "drinking" and "smoking", the results showed that households in which smokers and drinkers were more likely to occur catastrophic health expenditure. However, since the analysis was not the regression of panel data, it was impossible to infer causality, which could only reflect the correlation between the two. Therefore, the possible reason may be that the members of families with catastrophic health expenditure were not allowed to smoke and drink due to their physical conditions and economic conditions, which showed that the probability of HCHE in families with smokers and drinkers was lower.

STRENGTHS AND LIMITATIONS

The paper is the first article to explore the policy effect of universal health insurance coverage process on Residents' disease economic burden in China by using data spanning 10 years (2008, 2013, and 2018). Additionally, Our sample is based on the whole population which will be more universal. Nevertheless, there are still some limitations. Firstly, it was not realistic to include all possible impact factors in our regression models, which may have led to oversimplification in our conclusions. Secondly, we used NHSS data from Jiangsu province, which may not be representative of the whole country. Finally, given that we used pooled cross-sectional data, we were unable to deduce causality.

CONCLUSION

Social health insurance had a significant positive effect on the annual THE and OOP and a significant negative effect on HCHE in urban and rural residents of Jiangsu province, China. However, universal health insurance coverage could alleviated the economic burden of disease on individuals (THE and OOP) while it was insufficient to protect against the economic risk of diseases (HCHE). There are still discrepancies between urban and rural areas in terms of the impact of health insurance; moreover, the economic burden of disease is greater for people living in

rural areas or who are elderly, less educated, have a lower income, are in poor health, or have chronic diseases. Therefore, the government should shift the emphasis of social health insurance from quantity to quality and take multiple measures to reduce the economic risks of disease—especially in these vulnerable groups—in order to promote the development of the economy and society.

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

This study was approved by the Academic Research Ethics Committee of Nanjing Medical University. All procedures were in accordance with the ethical standards of the Helsinki Declaration. Participants provided informed consent prior to data collection.

AUTHOR CONTRIBUTIONS

SZ, CZ, QY, and ZW: conceptualization, methodology, and software. SZ, QY, and ZW: validation, formal analysis, investigation, and writing—review and editing. ZW: data curation, supervision, and project administration. SZ and CZ: writing—original draft preparation. All authors have read and agreed to the published version of the manuscript.

FUNDING

This research was funded by the Excellent Innovation Team of the Philosophy and Social Sciences in the Universities and Colleges of Jiangsu Province.

ACKNOWLEDGMENTS

We would like to acknowledge Chinese National Health Commission and local Health Commission of Jiangsu province for their cooperation. We would also like to thank all study participants for their time to be interviewed.

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frontiers | Frontiers in Public Health

ORIGINAL RESEARCH
published: 06 April 2022
doi: 10.3389/fpubh.2022.866324

How Two-Child Policy Affects China's Energy Consumption: The Mediating Role of Lifestyle

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Background: Existing literature believed that the birth control policy affects energy consumption through the change in population size, but ignored the changes in people's lifestyle. This may mislead the government's policy-making about population and energy consumption.

Method: This article proposed a Population-Lifestyle-Energy (PLE) model to provide new insights into how birth control policy affects energy consumption if the changes in people's lifestyle are considered. The ProFamy software is used to forecast the changes in demographic characteristics. The methods of regression analysis and Input-Output Analysis are used to predict the impacts of lifestyle changes on energy consumption.

Results: We find that China's two-child policy will result in the total energy consumption increase by 16.2% in 2050, far outpacing the population increase of 9.3% when considering the indirect effect of lifestyle changes. This is significantly different from the optimistic wisdom in the existing literature. We also find the non-linear relationships between fertility rate and energy consumption.

Conclusion: Ignoring lifestyle changes will lead to an underestimation of energy consumption. Contrary to conventional optimistic wisdom, we believe that the two-child policy will make it difficult for China to meet promised energy conservation goals.

Keywords: two-child policy, lifestyle, energy consumption, fertility rate, scenario analysis

OPEN ACCESS

Edited by:
Jianhong He,
Chongqing University of Posts and Telecommunications, China

Reviewed by:
Hao Wu,
Nanjing Normal University, China
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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *31 January 2022*
Accepted: *04 March 2022*
Published: *06 April 2022*

Citation:
Chen F, Wang W, Wang Y and Wu Y (2022) How Two-Child Policy Affects China's Energy Consumption: The Mediating Role of Lifestyle. Front. Public Health 10:866324. doi: 10.3389/fpubh.2022.866324

INTRODUCTION

The mounting need for energy use portends hazardous consequences on human health (1). The population is one of the most important factors that determine energy consumption (2, 3). China is the most populous and the most energy-consuming country in the world (4). After the implementation of the one-child policy in the 1970's, the birth rate continued to fall, far below the world average. Therefore, many studies believed that the declining fertility rate would lead to a decrease in energy consumption in China (5, 6). However, the Chinese new birth control policy is changing the trend of population growth. In 2010 (the last year of the one-child family policy), the birth rate was only 11.9 per thousand, and the second child and above accounted for 44.1% of newborns. In November 2011, China implemented a two-child fertility policy for couples where both the husband and the wife are from a single-child family. In January 2016, China replaced the one-child policy with the universal two-child policy. In 2020, there were 12.02 million

newborns in China, of which the second- or multi-child accounted for 57.6%. Although the two-child policy has made a significant increase in the fertility rate and population size, few works of literature have concerned the potential challenges posed by the two-child policy to China's energy consumption (7).

Many works of literature have studied the impact of population size decided by the fertility rate on energy consumption (8–13). However, these studies had an obvious defect, as they were based on the assumption of "representative households/individuals," i.e., all individuals and households have the same lifestyle and consumption pattern (14–16). In other words, the traditional assumption focused on the change in population size but unfortunately ignored the changes in people's lifestyle (17, 18). Actually, the fertility rate not only changes population size but also changes the people's lifestyle (e.g., household size, consumption pattern, and travel style) (19–21). The changes in lifestyle will have an important impact on energy consumption (16, 22). For example, residential energy consumption (REC) is decided by both the household number and household type[1] (12, 21, 23). Because the fertility rate will not change the number of households in the short run, only the household type (21), the REC will be mis-estimated if the changes of household type are ignored.

The existing literature has focused on the effect of population size on energy consumption and ignored the mediating effect of lifestyle changes (8, 9, 12, 24, 25). This article tried to comprehensively analyze the impact of birth control policy on energy consumption by considering the changes in the population size and people's lifestyles. We find that lifestyle changes cannot be ignored in energy consumption forecast, and the impact of fertility rate on lifestyle and energy consumption varies across end-users. Firstly, the two-child policy will change the household size in the residential sector. The traditional literature classified household types by the intergenerational structure (3, 16, 26). However, the two-child policy will not change the intergenerational structure in the household in the short term but will increase the household size.[2] Therefore, the impact of the two-child policy on the REC can only be found through the changes in household number and household size. Secondly, the two-child policy will change the quantity and structure of the demand for goods and services, because of the different lifestyles in the different life cycle stages. Then energy consumption in the industrial and commercial sectors and freight transport sector will change accordingly. Thirdly, the travel style is different for the people in the different life cycle stages. We will study the impact of travel style on energy consumption in the passenger transport sector, which was neglected in traditional works of literature (27, 28). Therefore, the impact of the two-child policy on energy consumption is not equal to the population growth when considering the changes in lifestyle. The findings of this study indicate that the two-child policy will change the trend of China's energy consumption and significantly impact the Chinese government in achieving the promise of energy conservation and emission reduction goals. We believe that the traditional view that the slowing population growth will reduce China's energy consumption in the future is overly optimistic (4, 8, 24). This article is among the first to reveal the transmission mechanism between fertility rate and energy consumption by simultaneously considering the dynamic changes of lifestyle and population size. This study has important implications for energy consumption forecasting and formulating the energy conservation policies of the governments and international organizations.

[1]The household types can be classified by the household size, intergenerational structure, age distribution, and so on.

[2]The existing works of literature classified the household types into the one-generation household, two-generation household, and three-generation household. The two-child policy will increase the number of the youngest generation, but will not change the type of household. Therefore, we cannot classify household types by the intergenerational relationships when studying the impact of the two-child policy on REC.

OBJECTIVES AND SCENARIOS

The target of this study was to quantify the impact of birth control policy on energy consumption in China. To address the aforementioned shortcomings of traditional research, this article presents a Population-Lifestyle-Energy (PLE) model to evaluate the impact of the fertility rate on energy consumption (**Figure 1**). Many works of literature have concerned the impact of the changes in consumer lifestyle on energy consumption (16, 29); etc.]. These studies mainly focused on the individual energy consumption (30), but ignored the effects on the enterprise sector (31). This study analyzes the mediating effects of lifestyle changes on energy consumption from three perspectives: household size, consumption structure, and travel mode. Compared with the traditional models (11), the PLE model will provide new insights into how fertility rate affects energy consumption by combining the micro survey data with the macro statistical data and reveals quantitative relationships among fertility rate, the changes of lifestyle, and energy consumption for different sectors.

In the existing models, there are different classifications for the end-user of energy. The most popular classification includes four sectors, i.e., residential, commercial, transportation, and industrial sectors [9; 10; etc.]. Since the industrial and commercial sectors used similar data and methods to predict the energy consumption in the PLE model, they were combined into one sector. Because the energy consumption in passenger transport and freight transport is predicted using different methods, the transport sector is divided into two sectors. Therefore, the end-user of energy is decomposed into four sectors, i.e., residential, industrial and commercial sector, passenger transport, and freight transport sector. This classification is consistent with the Structure of Extended Snapshot Tool (ExSS) (17).

The birth control policy produces a "direct effect" on the residential and passenger transport sectors. In the residential sector, the PLE model abandons the assumption of standardized household and simultaneously considers the changes of the household number and household size (21, 26). In the passenger transport sector, the two-child policy will affect

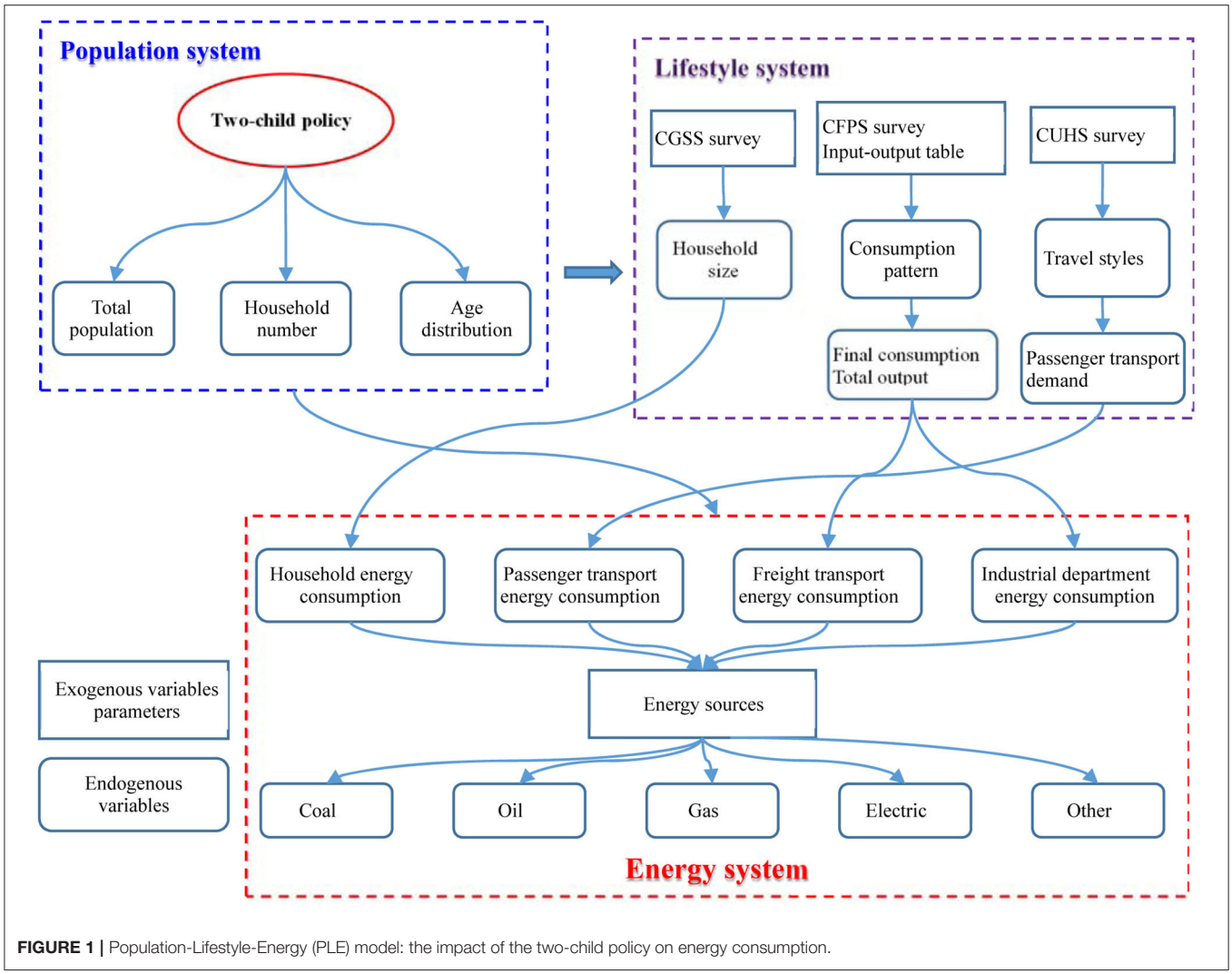


FIGURE 1 | Population-Lifestyle-Energy (PLE) model: the impact of the two-child policy on energy consumption.

the passenger transport demand and its structure due to the differences in travel mode among different life cycle stages (28).

The birth control policy produces an "indirect effect" on the industrial and commercial sectors and freight transport sector. In the industrial and commercial sectors, the two-child policy will change the consumption pattern, thus affecting the demand for goods and services. Then the energy consumption can be estimated by the Input-Output Table Analysis (19, 20, 22). Energy consumption in the freight transport sector is decided by the goods and service demand of the industrial and commercial sectors (32) and is also estimated by the Input-Output Table Analysis.

In the PLE model, the first step of the energy demand forecast is to predict the demographic characteristics. China has implemented the universal two-child policy since 2016. The new birth control policy would lead to a sharp increase in the number of two-child births (7). To assess the impact of the new policy on energy consumption, we simulate two different variations that assume different fertility policies.

Scenario I

The old birth control policy (one-child policy). Each couple can have only one child. According to the *Chinese Population and Family Planning Law*, each illegal extra child would be fined 3–10 times of his/her annual income. In 2010, the total fertility rate in the rural areas was 1.80, with the fertility rates of one-child, two-child, three-child, and more being 0.943, 0.675, and 0.164, respectively; the total fertility rate in the urban areas was 1.22, with the fertility rates of one-child, two-child, three-child, and more being 0.854, 0.320, and 0.046, respectively. In Scenario I, we assume that the total fertility rate and the distribution in urban and rural areas remain constant.

Scenario II

The new birth control policy (two-child policy). Under the new birth control policy, every couple can have two children. Due to the concentrated outbreak of the accumulated fertility desire, the two-child fertility rate was very high in the early stage of the implementation of the policy. In 2019, the number of two-child births exceeds the number of one-child births.

Therefore, population projections based on fertility rates in recent years are unreliable. Referring to the survey results of fertility preference (33), we make the following assumption in Scenario II: (1) the two-child policy will not affect the first child fertility rate; (2) the total fertility rate in the rural areas is 2.140, with the fertility rates of one-child, two-child, three-child, and more being 0.943, 0.963, and 0.234, respectively; (3) the total fertility rate in the urban areas is 1.808, with the fertility rates of one-child, two-child, three-child, and more being 0.854, 0.834, and 0.120, respectively.

The following discussion concentrates on the impact of the two-child policy on population characteristics and energy consumption, drawing comparisons with the scenario of the one-child policy remaining in place. Since the two-child households are formed from the one-child households, the new birth control policy will not change the intergenerational structure of households in the short term, but only change the household size. The two-child policy will only lead to an increase in the household number when the new births grow up and leave the parental home. In the scenario prediction, we take 2016 as the benchmark year, when China began to implement the universal two-child policy. Being the final year of our analysis 2050, people born after 2016 will come of age. Although we have not analyzed the trend across the life cycle, this study can provide effective evaluation for the influence of the two-child policy and the knowledge to guide policy-making.

The ProFamy software is used to predict the changes in demographic characteristics during 2016–2050 (34)[3]. The original data and model parameters are derived from the sixth census and the annual sampling survey data,[4] including probabilities of surviving, marital status transitions, age-specific fertility frequencies, life expectancies at birth, mean ages at birth, mean ages of children leaving the parental home, proportions of elderly living with children, and sex ratio at birth. The data of future urbanization rates are collected from the Human Development Report 2019 (35).

METHODOLOGY

The energy consumption of four sectors, namely, the residential sector, industrial and commercial sectors, passenger transport sector, and freight transport sector, are predicted using different methods and data.

Model of the Residential Sector

Referring to the existing references (36), the number of the standardized households for different energy types is calculated by the following equation:

$$THI_{et,reg} = \sum_{ht=1}^{7} \left(HN_{ht,reg} \times HI_{et,reg,ht} \right), \quad (1)$$

Where,

et is energy type including coal, oil, natural gas, electricity, and other energy sources.

reg is regions (including urban and rural). There are different energy consumption patterns between urban and rural residents in China (16).

ht is household type divided into 7 groups according to the persons per household: 1–6 persons and more than 7 persons.

HN is the number of household, which is predicted by the ProFamy software (34). The parameter assumption has been introduced in Section Objectives and scenarios.

HI is the energy consumption index for different household types. The data are calculated using the Chinese General Social Survey (CGSS) database (**Supplementary Table 1**)[5]. The one-person household is assigned as the standard household (*HI = 100*). The household energy consumption does not increase in proportion to the persons per household. The larger the household size, the lesser the energy consumption per person. Other types of households can be converted to the standard households according to the *HI*.

THI is the total number of standardized households, which is classified by the different energy types.

The calculation formula of total energy consumption in the residential sector is

$$REC_{et} = \sum_{reg} \left(THI_{et,reg} \times AHI_{et,reg} \right), \quad (2)$$

Where,

$AHI_{et,reg}$ is the average energy consumption for a standardized household. The *AHI* is predicted by Logistic Model on the basis of historical data except for the coal consumption in the rural regions (**Supplementary Figure 1**). Due to the accelerated construction of the natural gas pipelines, the use of natural gas will significantly increase in the future (37). Due to the popularity of household electrical appliances, the electricity consumption will also significantly increase (38). Because of the stricter environmental policy and wide use of home appliances (4), the consumption of coal in the future Chinese families will continue to decline. Therefore, the *AHI* of coal in the rural region is predicted by the Linear-Quadratic Model.

REC_{et} is the residential energy consumption for different energy types. It is the sum of the rural and urban regions.

Model of Industrial and Commercial Sectors

Firstly, resident's demand for goods and services is calculated according to the population size and per capita consumption. Considering the changes of population size and structure, the growths of consumption expenditure in different industrial and commercial sectors are

[3]The website of ProFamy software: http://www.profamy.com.cn/.

[4]The Chinese Sixth National Population Census data are available at: http://www.stats.gov.cn/tjsj/pcsj/rkpc/6rp/indexch.htm.

[5]Data were derived from the Chinese General Social Survey (CGSS) (2017), collected by the Department of Sociology at Renmin University of China. The original data are available at: http://cgss.ruc.edu.cn/index.php?r=index/index&hl=en.

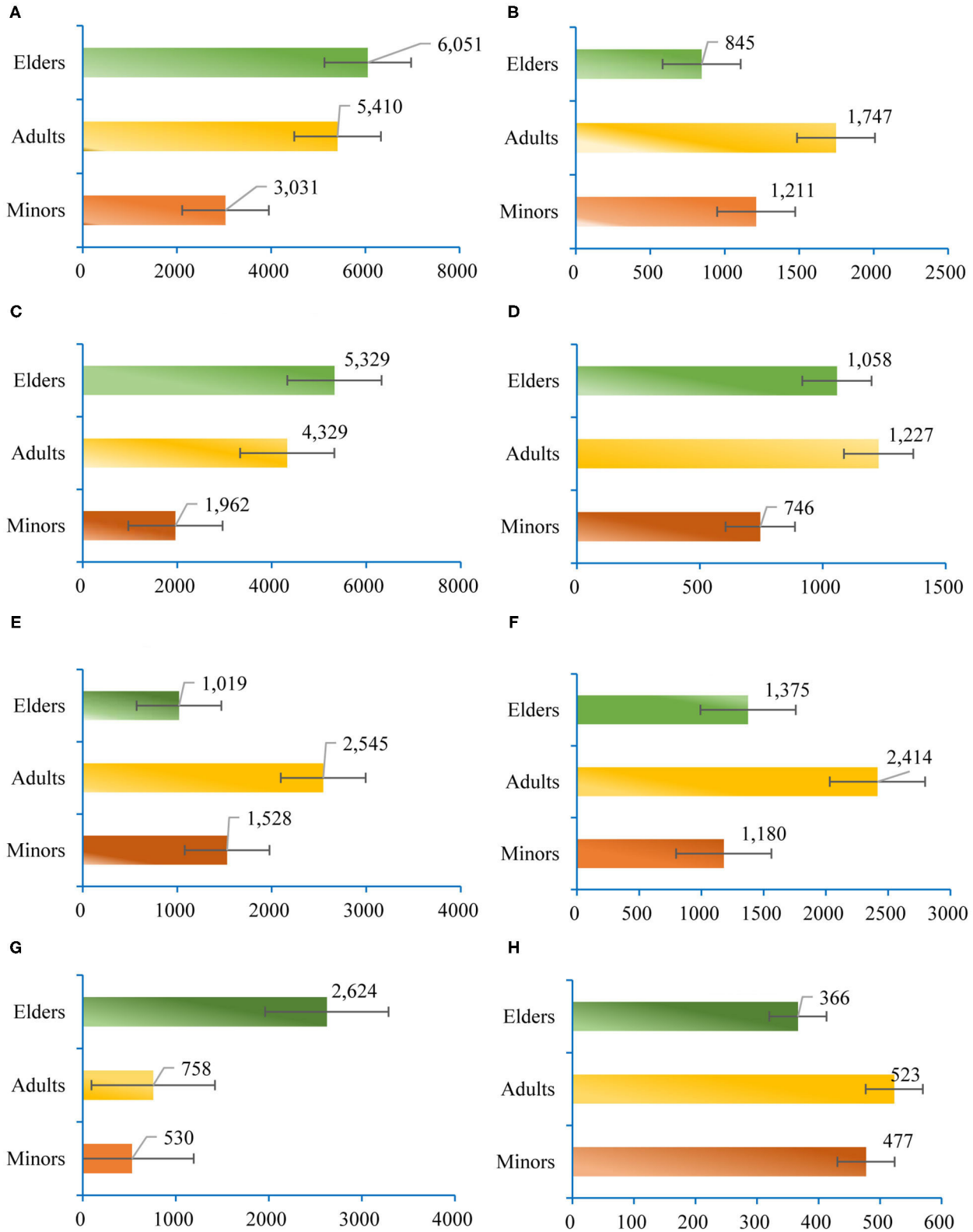


FIGURE 2 | Demand for goods and services in different life cycle stages (Unit: CNY). **(A)** Expenditure on food, tobacco, and alcohol. **(B)** Clothing expenditure. **(C)** Housing expenditure. **(D)** Expenditure on facility and services. **(E)** Expenditure on communication and transportation. **(F)** Expenditure on education and entertainment, and cultural activities. **(G)** Healthcare expenditure. **(H)** Expenditure on miscellaneous goods and services.

$$GDC_{reg,id,t} = \frac{\sum_{life} POP_{life,reg,t} \times CON_{life,reg,id}}{\sum_{life} POP_{life,reg,2017} \times CON_{life,reg,id}}, \quad (3)$$

Where,

id denotes the goods and service categories, which are divided into eight aspects (16): (1) food, tobacco, and alcohol, (2) clothing, (3) housing, (4) facility and services, (5) communication and transportation, (6) education and entertainment and cultural activities, (7) healthcare, and (8) miscellaneous goods and services.

t is the year.

life is life cycle stages, including minors, adults, and elders.[6] People's lifestyles are different in different life cycle stages.

POP is the population size, which is predicted by the ProFamy software (34).

CON is the index of consumption expenditure per capita for different life cycle stages. The data are derived from the China Family Panel Studies (CFPS) database[7]. Minors have less consumption expenditure than other groups for the most goods and services. The elders have the fewest expenditure on clothing, communication, and transportation (**Figure 2**).

GDC represents the growth of consumption expenditure caused by the demographic changes (**Supplementary Figure 2**). Affected by urbanization (11), the consumption expenditure in the rural regions will decrease, while the urban regions will increase. Due to the changes in demographic characteristics, residential consumption expenditure on communications, transportation, and clothing grew slowly, but healthcare expenditure is the fastest growing.

Then, the consumption expenditure of urban and rural regions is calculated by,

$$GCI_{reg,id,t} = \frac{WP_{reg,t} \times GPW_{reg,t} \times CP_{reg,id,t}}{WP_{reg,2017} \times GPW_{reg,2017} \times CP_{reg,id,2017}}, \quad (4)$$

$$GHC_{reg,id,t} = GDC_{reg,id,t} \times GCI_{reg,id,t}, \quad (5)$$

Where,

WP is the working-age population, which is predicted by the ProFamy software.

GPW is GDP per-worker, which is estimated according to the EIA prediction (10) (**Supplementary Table 2**).

CP is the propensity to consume, which is estimated according to the experience of European Union Nations (39) (**Supplementary Table 2**).

GCI is the growth of consumption expenditure caused by the income increase. It represents the influence of exogenous economic growth.

GHC is the growth of household consumption expenditure (HCE), including rural regions and urban regions. It represents the total growth of consumption expenditure caused by demographic changes and economic development.

Secondly, the method of Input-Output Analysis is used to estimate the energy demand in the industrial and commercial sectors (38). China's Input-Output Table subdivided goods and services into 149 sectors. The most recent table in 2017 is used to calculate the total output and intermediate input of each sector. Government consumption expenditure (*GCE*) and total capital formation (*TCF*) are assumed to increase year-on-year with the residents' final use, regardless of the changes in imports and exports. The *HCE* is calculated as

$$HCE_{reg,se,t} = HCE_{reg,se,2017} \times GHC_{reg,se,t}, \quad (6)$$

Where,

reg represents the rural or urban region.

se represents 149 sectors in the Input-Output Table. Because *GHC* is classified into 8 categories, the value of $GHC_{reg,se,t}$ is assigned according to the categories (*id*) to which each sector (*se*) belongs.

According to the final use matrix and the consumption coefficient table of input product, the final total expenditure is calculated by

$$TI_t = (HCE_t + GCE_t + TCF_t) \times (I - CCM)^{-1}, \quad (7)$$

Where,

HCE is the sum of household consumption expenditure in urban and rural regions.

In Equation (7), *HCE*, *GCE*, and *TCF* are all in vector forms of 149 sectors.

I is 149*149 unit matrix.

CCM is a consumption coefficient matrix and is assumed to remain constant.

TI_t is the total input vector for 149 sectors in the future (**Supplementary Figure 3**).

Finally, the consumption of various energy types is estimated. Because the Input-Output Table is the monetary measurement, the energy consumption in physical measurement can be derived from:

$$ECI_{et,t} = \frac{TI_{et,t}}{TI_{et,2017}} \times ECI_{et,2017}, \quad (8)$$

Where,

$TI_{et,t}$ is the total input for five types of energy including coal, oil, natural gas, electricity, and other energy sources. The data of $TI_{et,t}$ are extracted from TI_t according to the corresponding sectors.

$ECI_{et,t}$ is energy consumption for energy type *et*.

Model of Passenger Transport Sector

First, the impact of population size and lifestyle changes on the passenger transport demand is estimated by:

[6]The life cycle is divided into three phases in this article: minors (under 14 years old), adults (15–59 years old), and elders (over 60 years old).

[7]The most recent data are collected in 2018 and are available at: https://opendata.pku.edu.cn/dataverse/CFPS.

$$PDC_{vt,reg,t} = \frac{\sum_{life} POP_{life,reg,t} \times TEI_{life,reg,vt}}{\sum_{life} POP_{life,reg,2017} \times TEI_{life,reg,vt}}, \quad (9)$$

Where,

vt is vehicle type for passenger transport, such as railway transport, road transport, waterway transport, and air transport.

TEI is the travel expense index for various vehicle types. People in different life cycle stages, namely, minors, adults, and elders, have different travel modes. The data are derived from the Chinese Urban Household Survey (CUHS) database.[8] The adult group is taken as the control group ($TEI = 100$). The travel expense index of the minor group is significantly lower than that of other groups. The elder group is second only to the adult group (**Supplementary Figure 4**). Since there is no rural household survey database, we assume that the travel expense index of the rural regions is the same as the urban regions.

PDC is the growth of passenger transport demand caused by the changes in demographics and lifestyle, and 2017 is the base year.

Second, assumed that the mileage per capital remains constant, the demand of total passenger transport can be calculated by

$$PK_{vt,reg,t} = PDC_{vt,reg,t} \times PK_{vt,reg,2017}, \quad (10)$$

Where,

PK is the demand of total passenger transport (passenger-kilometer) for different vehicle types and regions.

Finally, according to the changes of passenger transport demand, the passenger transport energy consumption for various vehicle types is calculated as follows:

$$ECV_{vt,et,t} = \sum_{reg} PK_{vt,reg,t} \times PET_P_{vt,et,t}, \quad (11)$$

$$ECP_{et,t} = \sum_{vt} ECV_{vt,et,t}, \quad (12)$$

Where,

$ECV_{vt,et,t}$ is the energy consumption of energy type *et* in different vehicles.

$PET_P_{vt,et,t}$ is the proportion of energy type *et* consumption in the vehicle *vt*. The data of *PET_P* are derived from the Input-Output Table.

$ECP_{et,t}$ is total consumption of energy type *et*.

Model of Freight Transport Sector

Using the data of the total input vector (*TI*), which is predicted in Equation (7), the freight transport demand for various transport tools can be calculated by

$$FDT_{ftt,t} = \sum_{se} TI_{se,t}, \quad (13)$$

Where,

ftt is freight transport tools, including railway freight transport, road freight transport, water cargo transportation, air cargo transport, and other transport tools.

se denotes the sectors in *TI* corresponding to the freight transport tools. The railway freight transport matches with the sector of "railway freight transport and transport support activities;" the road freight transport match with the sector of "road freight transport and transport support activities;" the water cargo transportation match with the sector of "water cargo transportation and transportation support activities;" the air cargo transport match with the sector of "air cargo transport and transport support activities;" the other transport tools match with the following sectors: "pipeline transportation," "multimodal transport and transport agents," "handling and storage," and "postal service."

FDT is the freight demand for different transport tools.

Then, the energy demand of each energy type and transport tools is calculated by

$$FDE_{ftt,et,t} = FDT_{ftt,t} \times FET_P_{ftt,et,t}, \quad (14)$$

Where,

$FET_P_{ftt,et,t}$ is the proportion of energy type *et* consumption in the freight transport tool *ftt*. The data are derived from the Input-Output Table.

FDE is the energy consumption of the different energy types and freight transport tools.

Finally, the energy consumption of each energy type *et* in the freight transport sector is

$$ECF_{et,t} = \sum_{ftt} \frac{FED_{ftt,et,t}}{FED_{ftt,et,2017}} \times ECF_{ftt,et,2017}. \quad (15)$$

RESULTS

Impact of the Two-Child Policy on Population and Lifestyle

The ProFamy software is used to predict the future population (34). If the one-child policy continues in China, the total population size in 2050 is expected to reach 1.244 billion, of which the urban population will be 0.913 billion, and the urbanization rate will be 73.4% (**Figure 3A**)[9]. These results are close to the forecast of the *Human Development Report 2019* (35). After implementing the two-child policy, the total population is estimated to reach 1.360 billion in 2050, and the urbanization will stand at 74.2%. Compared with the old birth policy, the new policy is estimated to result in an increase of 14.3 million persons in 2020 and an increase of 116.0 million persons in 2050.

Because of the changes in work style and ideology, the size of China's households will slowly decrease in the future

[8]The data in 2015 are available at: https://microdata.stats.gov.cn/.

[9]*Human Development Report 2019* forecasted the global urbanization rate was estimated to grow to nearly 70% by 2050.

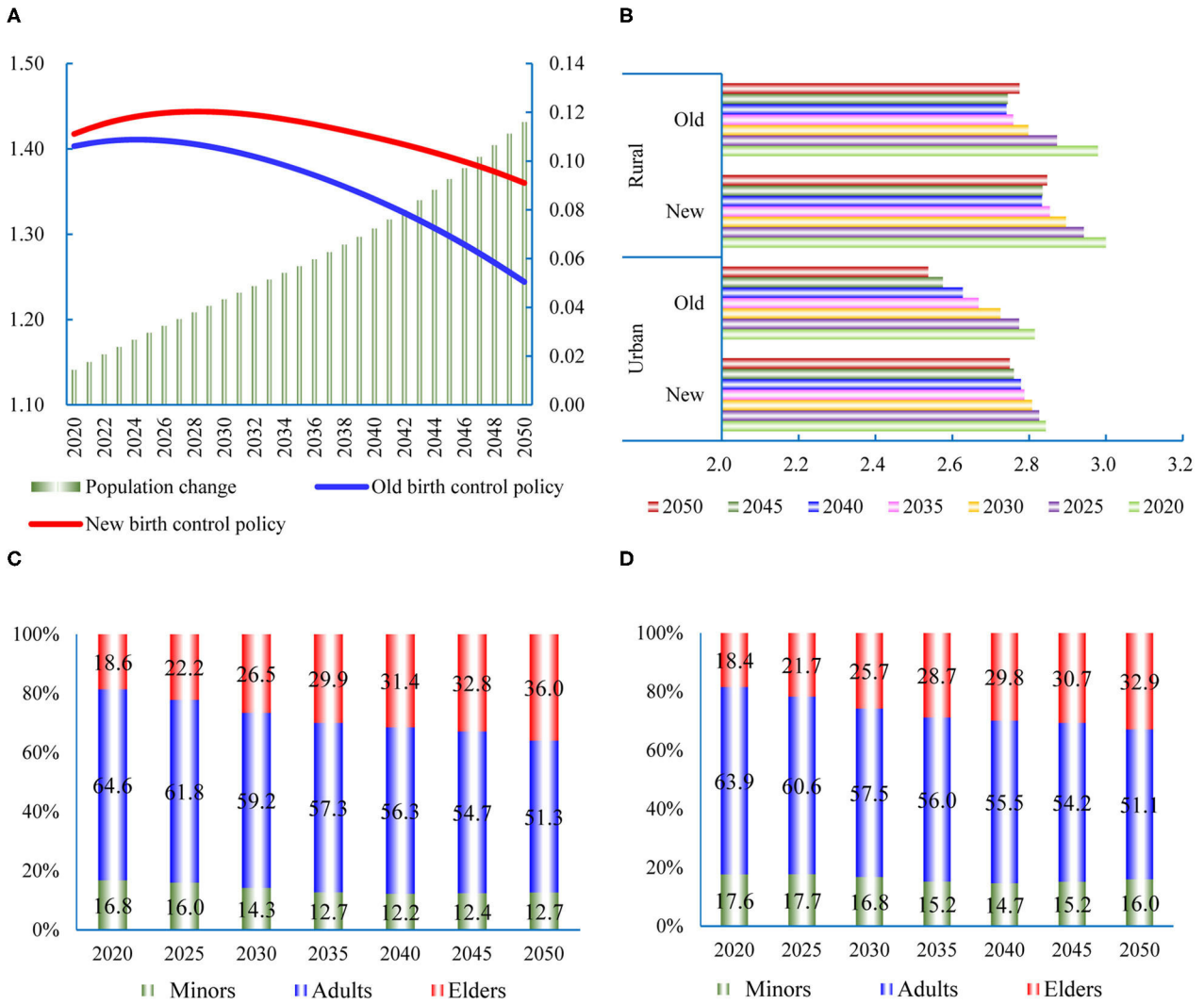


FIGURE 3 | Changes of population characteristics and household size. **(A)** The changes of population size (billion persons). **(B)** Average household size (persons). **(C)** Population distribution for different life cycle stages in old policy. **(D)** Population distribution for different life cycle stages in new policy.

(40, 41). However, the two-child policy will delay this trend (**Figure 3B**). If the two-child policy is not implemented in the urban region, the average household size will slowly drop to 2.54 in 2050. However, after the implementation of the two-child policy, the household size will remain at the level of 2.75. The household size in the rural regions will increase by 0.07 in 2050, which is smaller than that in the urban regions. The main reason is that the Family Planning Law has not been strictly abided in the rural region. The two-child policy will change the population in different life cycle stages (**Figures 3C,D**). In 2050, the new policy will reduce the proportion of elders (over 60 years old) by 3.1% and increase the proportion of minors (under 14 years old) by 3.3%. Many studies confirmed that population aging can reduce energy use (42). We can infer that the new birth control policy in China will increase the energy consumption per capita because of the decline of the elderly population proportion. It will increase the challenge in achieving the target of Chinese carbon emission.

Energy Consumption in the Residential Sector

In **Figures 4A,B**, the average energy consumption for different types of households is shown (one-person household is the standard household). These statistics indicate that energy consumption per household is not proportional to household size. It has a significant scale effect that energy consumption per person is declining with the expansion of household size. Taking the electricity consumption as an example, the two-person household is 148.0% of the standard household; the three-person household is 170.5% of the standard household, and the

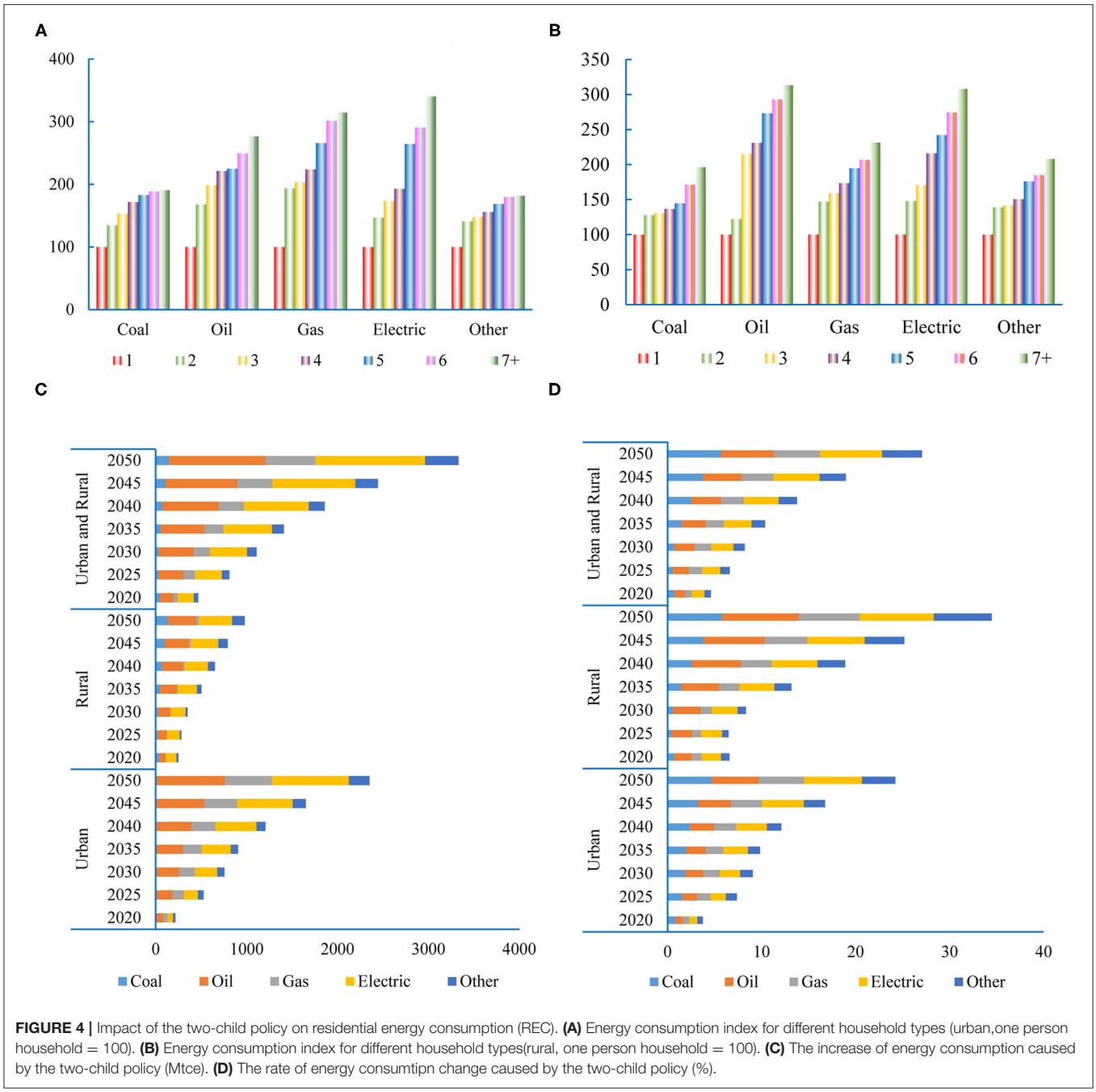


FIGURE 4 | Impact of the two-child policy on residential energy consumption (REC). **(A)** Energy consumption index for different household types (urban,one person household = 100). **(B)** Energy consumption index for different household types(rural, one person household = 100). **(C)** The increase of energy consumption caused by the two-child policy (Mtce). **(D)** The rate of energy consumtipn change caused by the two-child policy (%).

household with more than seven persons is 307.9% of the standard household.

Using the prediction of the household number and household size, we can estimate the REC in Scenario I and II, respectively. The impact of the new birth control policy on REC is small in the short term and will increase over time (**Figure 4C**). In 2020, when compared to the one-child policy, the new policy will lead to an increase in REC by 4.69 Mtce (the rate of change is 1.01%)[10]; in which urban region will increase by 2.18 Mtce (the rate of change is 0.75%) and rural region will increase by 2.51 Mtce (the rate of change is 2.25%). By 2050, the impact of the two-child policy changes on the resident's energy consumption will reach 33.31 Mtce, an increase of 5.59%, of which urban region will increase by 23.52 Mtce, accounting for 70.6%; rural region will increase by 9.79 Mtce, accounting for 29.4%. The impacts of the two-child policy on different types of energy consumption are shown in **Figure 4D**. In 2050, the two-child policy will result in a 9.33% increase in population, but the energy consumption will only increase by 5.59%. The reason is that the expansion of household size leads to the decline of energy consumption per capita.

[10]Here is a comparison with the old fertility policy, hereinafter.

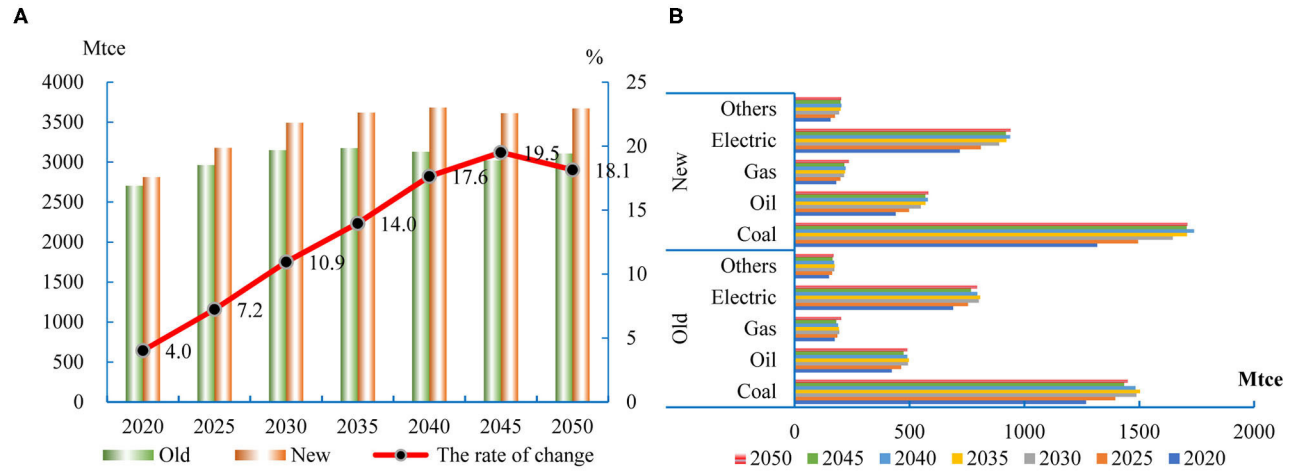


FIGURE 5 | The energy consumption in the industrial and commercial sectors. **(A)** The changes of energy consumption in industrial and commercial sectors. **(B)** The changes of different energy types.

Energy Consumption in the Industrial and Commercial Sectors

People in different life cycle stages have different consumption patterns (20). The demand for goods and services is affected by the population size and structure. The consumption of goods and services decides the energy input of industrial and commercial sectors. The results of the Input-Output Table Analysis indicate that the impact of the two-child policy on the energy consumption of industrial and commercial sectors changes dynamically over time (**Figure 5A**). In 2050, the two-child policy will result in an 18.1% increase in energy consumption in the industrial and commercial sectors. The electricity consumption will be the most affected, and the gas will be the least affected (**Figure 5B**). The growth of energy consumption exceeds the population growth. There are three reasons for the result. Firstly, the two-child policy will promote urbanization, and urban residents have greater consumption expenditure per capita. Second, the two-child policy will mainly increase the number of minors in the short term. Since minors have no income, this will increase the marginal propensity to consume. Third, the increase of the working-age population will promote economic development and increase residential income, which will lead to the increase of total consumption expenditure.

Energy Consumption in the Passenger and Freight Transport Sectors

According to the results in **Figure 6A**, the two-child policy leads to an increase in energy consumption in the passenger transport, but it is not keeping pace with the population growth. Before 2030, the growth of energy consumption is smaller than population growth, because most of the newborn population are minors. In 2030, the new policy will lead to a 2.04% increase in energy consumption in the passenger transport, which is obviously lower than population growth (3.10%). Then, as the newborn population grows up, the growth rate of energy consumption in the passenger transport is gradually converging with population growth. Given that the minors have a lower travel demand than adults and elders (43), the growth of energy consumption will be lower than population growth before 2050. In 2050, the total energy consumption of the passenger transport sector will be 270 Mtce in the old policy. The changes caused by the two-child policy will increase the energy consumption to 22.3 Mtce. The rate of increase is 9.0%, which is close to the population increase caused by the two-child policy.

The energy consumption of the freight transport sector is closely related to the development of the industrial and commercial sectors. **Figure 6B** shows the dynamic process of energy consumption in the freight transport sector. In the old birth control policy, the total energy consumption of the freight transport sector in 2050 is expected to be 1,493 Mtce. The new birth policy will increase energy consumption by 189 Mtce. The rate of increase is 14.5% exceeding the population growth.

Decomposition of Total Energy Consumption

Combined with the energy consumption in the four sectors, the terminal energy consumption will reach 6,107 Mtce in 2050 in Scenario II (the two-child policy is implemented), an increase of 16.2% when compared with Scenario I (**Supplementary Figure 5**). Since the industrial and commercial sectors accounted for 75.3% of China's final energy consumption, the contribution of the "indirect effect" greatly exceeds the "direct effect" caused by the residential and passenger transport sectors. Finally, the growth of total energy consumption is significantly higher than the population growth. There are two transmission routes of the two-child policy affecting energy consumption. One is that an increase in population size leads to an increase in energy consumption. Another is that the changes in lifestyles change the energy consumption scale and structure. Therefore, the growth of total energy consumption can be

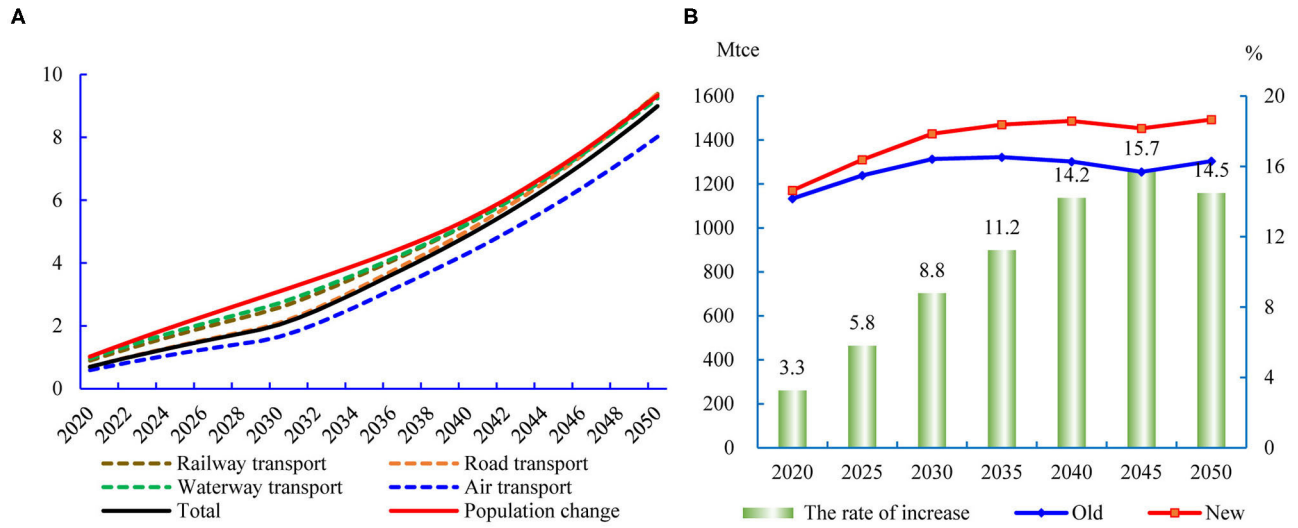


FIGURE 6 | Effect of the two-child policy on energy consumption in the transport sector. **(A)** The changes of energy consumption in the passenger transport sector (%). **(B)** Energy consumption in the freight transport sector.

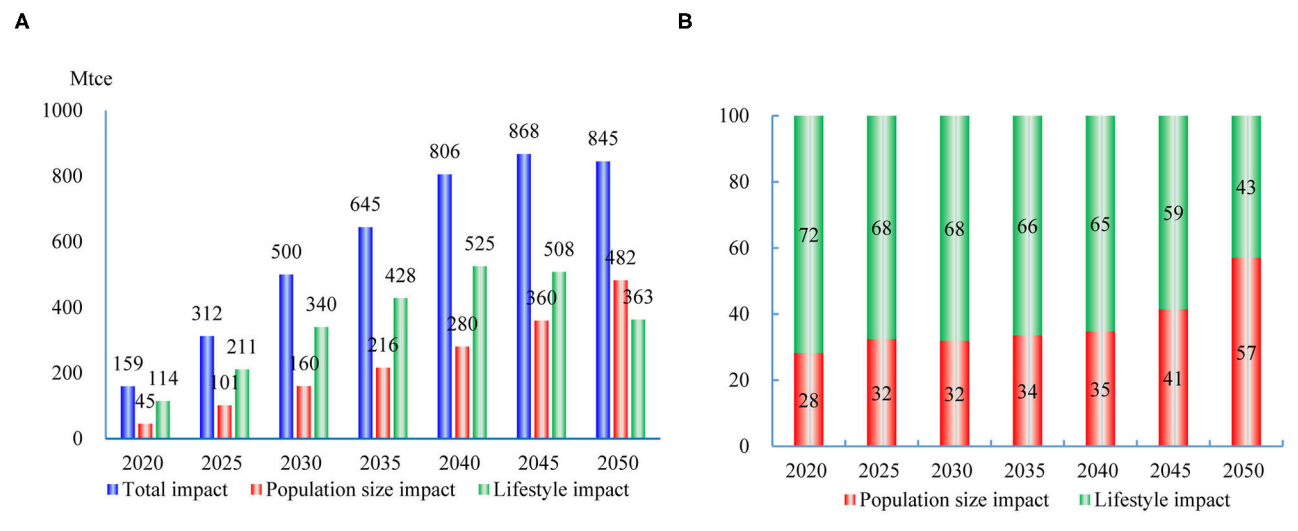


FIGURE 7 | The factor decomposition of the total energy consumption changes. **(A)** The decomposition of total energy consumption changes. **(B)** The contributions of different impact factors to energy consumption (%).

decomposed into the impacts of population sizes and lifestyle change. The impacts of lifestyle change are calculated by

$$(1 + TEC) = (1 + IPS) \times (1 + ILC), \quad (16)$$

Where,

TEC is the growth of total energy consumption.

IPS is the growth of population size. It reflects the impact of population size on energy consumption.

ILC is the impact of lifestyle changes on energy consumption.

The factor decomposition results show that the contribution of lifestyle changes continues to decline (**Figure 7A**). In 2020, the two-child policy increases energy consumption by 159 Mtce, in which the change in population size contributes 28%, but the change in people's lifestyle contributes 72%. In 2050, the two-child policy increases energy consumption by 845 Mtce, in which the change in population size contributes 57%, but the contribution of lifestyle change reduces to 43% (**Figure 7B**). The two-child policy has also changed the energy structure (**Supplementary Figure 6**). The main reason for these phenomena is that the two-child policy will mainly increase the number of minors in the short term. This makes the impact of the lifestyle changes on energy consumption is greater than the population growth. However, the mediating effect

of lifestyle changes will gradually decrease with the newborns growing up.

DISCUSSION

This article studies the impact of birth control policy on energy consumption from the new perspective of lifestyle changes. The PLE model analyzes the dynamic changes in China's energy consumption from 2020 to 2050. The impacts of the two-child policy on energy consumption in different sectors are as follows. Firstly, different from the existing works of literature (9), this article finds that the REC growing more slowly than population size because of the expansion of household size. In 2050, the two-child policy will lead to a 33.31 Mtce increase in REC, in which the increase in population size contributes 53.67 Mtce and the expansion of household size contributes −20.35 Mtce. Secondly, the two-child policy will increase the marginal propensity to consume and promote economic development (20), resulting in the "indirect effect" on energy consumption in the industrial and commercial sectors and freight transport sector. In 2050, the new policy will increase energy consumption by 18.1% in the industrial and commercial sectors and 14.5% in the freight transport sector, far outpacing a population increase of 9.3%. Thirdly, considering that the travel demand of minors is lower than that of adults and elders (44), the growth of energy consumption in the passenger transport sector is anticipated to be lower than that of the population until 2030. However, in the long term, the growth of passenger transport energy consumption will synchronize with population growth. Synthesizing the "direct effects" and "indirect effects," the impact of the two-child policy on total energy consumption significantly exceeds population increase when considering the changes in lifestyle. The two-child policy will lead the total energy consumption to increase by 16.2% in 2050, far outpacing the population size increase of 9.3%.

Many studies have held an optimistic attitude toward the future trend of energy consumption and carbon emissions in China (4, 24). The main reason is that the decline in China's population and population aging are becoming increasingly prominent (8, 45). Some works of literature even suggested that the aging population will reduce energy consumption, which is equivalent to the effect of technological change (5, 42). The results of this article, however, show that the previous view is overly optimistic. The two-child policy not only increases the total population but also changes people's lifestyle, which leads to the increase of energy consumption to exceed the expectation. As China is the most populous and the most energy-consuming country (4), the new policy will have a negative impact on global climate change mitigation.

There are three main contributions in this article when compared with the existing literature (4, 16, 23, 46), Firstly, new transmission mechanisms for the impact of birth control policy on energy consumption are proposed. The conventional wisdom holds that the fertility rate affects energy consumption only through the change in population size (8, 9, 12). The people's lifestyle is identified as another significant transmission route in this article. We also find that the impacts of lifestyle changes on energy consumption vary greatly across the four sectors. Secondly, we discover the non-linear relationship between the fertility rate and energy consumption by the dynamic analysis. In traditional static scenario analysis, the dynamic impact of the fertility rate on energy consumption cannot be observed (16, 24). The PLE model considers the changes in people's lifestyles in different life cycle stages and estimates the non-linear influence of the lifestyle changes on energy consumption. Thirdly, this study provides a new framework to predict energy consumption across the world. Energy consumption forecasting is an important prerequisite for energy policy-making. However, the popular models adopted by governments and international organizations ignore the lifestyle change caused by the birth control policy (10, 11). As a result, biased energy consumption forecasting might mislead policy-making. This study will be helpful to improve the traditional energy forecasting models.

Meanwhile, it is important to note that all the predictions are based on the current energy use efficiency. This study has not considered the changes in energy structure and energy intensity resulting from technological progress (47).

CONCLUSION AND POLICY IMPLICATIONS

This article presents the PLE model to study how birth control policy affects people's lifestyle and energy consumption. We find that the trend of energy consumption is significantly different from that predicted by traditional literature when considering the changes in lifestyle. The expansion of household size caused by the two-child policy will reduce REC by 3.42%. The energy consumption will grow more slowly than the population in the passenger transport sector, because the minors have less travel demand than adults and elders. The "indirect effect" (in the industrial, commercial, and freight transport sectors) will result in energy consumption that exceeds population growth. On the whole, the two-child policy will increase total energy consumption by 16.2% in 2050, far outpacing a population increase of 9.3%. In other words, ignoring lifestyle changes will lead to an underestimation of energy consumption. Contrary to conventional optimistic wisdom, we believe that the two-child policy will make it difficult for China to meet promised energy conservation goals, which deserves close attention from Chinese policy makers. This article is the first to fully reveal the transmission mechanism between birth control policy and energy consumption by considering the changes of lifestyle and population size simultaneously. The methods and findings have important implications for global energy consumption forecasting and policy making. Governments and international organizations should pay attention to the changes in lifestyles caused by the new birth control policy.

In conclusion, the two-child policy will change the trend of China's energy consumption and may cause the Chinese

government to miss its promise of peaking the energy consumption by 2030 (48). Therefore, the Chinese government needs to implement more effective policies to meet the challenge of population growth. Implementing more stringent energy conservation measures and improving energy efficiency further are the solutions. Based on the above conclusions, the following policy implications are proposed. Firstly, the government needs to reassess the plans for energy production and supply. China's energy supply is controlled by the government and the state-owned enterprises. Because the two-child policy will lead to a larger-than-expected increase in energy consumption in the future, governments need to increase energy production and supply over time. Secondly, the energy sources of REC must be optimized. At present, the proportion of coal consumption in REC is excessively high (35.6 and 3.7% in the rural and urban areas, respectively) (26). Because coal has a lower energy transfer efficiency (37), the "coal to gas" project should be widely implemented in rural areas. Meanwhile, the grown-up minors can be encouraged to live with their parents to make a scale effect and save REC. Thirdly, the industrial and commercial sectors are the main users of energy. It is critical to reduce energy intensity. The feasible measures include improving energy efficiency and reducing the consumption of energy-intensive goods. The Chinese government needs to phase out some energy-intensive industries and equipment that fail to meet energy efficiency standards (49, 50) and encourage people to use energy-efficient products. Finally, improving the share of public transport is an effective approach to reduce transportation energy consumption. The government can develop the shared mobility model in densely populated cities. In rural areas, meeting the travel needs of the elders and minors and reducing the proportion of private trips are reasonable.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

FC and YWu: designed the study. FC and YWa: contributed to data acquisition. WW and YWa: contributed to data analysis. YWa and YWu: wrote the original manuscript. WW and YWu: revised the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

FUNDING

This work was supported by National Social Science Fund of China (Grant No.18BJY050), China Association of Higher Education (Grant No. 21YDD05), and General Program of National Natural Science Foundation of China (Grant No. 72172020).

ACKNOWLEDGMENTS

We thank the Department of Sociology of Renmin University of China, Institute of Social Science Survey of Peking University and National Bureau of Statistics of China for making the data available.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.866324/full#supplementary-material

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frontiers | Frontiers in Public Health

ORIGINAL RESEARCH
published: 11 April 2022
doi: 10.3389/fpubh.2022.861897

Smartphone Use, Technology Affordance for Healthcare and Elders' Life Satisfaction

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Previous studies have examined how smartphones influence the life satisfaction of the elderly, but the existence of conflicting conclusions suggests the existence of a "black box". In this study, using a survey from 941 elders, we examine whether smartphone use can improve life satisfaction of the elders by inducing emotional affordance offered by social networking Apps and functional affordance offered by healthcare system Apps. It is found that both emotional affordance and functional affordance acted as intermediating variables between the use of smartphone and elders' life satisfaction. In addition, it is founded that living arrangement with adult children moderates the positive impact of smartphone use on functional affordance, but there was no such moderating effect on emotional affordance. This study offers insights about how digital healthcare innovation will be applied to increase well-being of elders by applying framework of selective optimization with compensation.

Keywords: smartphone use, emotional affordance, functional affordance, elders' life satisfaction, living arrangement, selective optimization with compensation

OPEN ACCESS

Edited by:
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Reviewed by:
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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *25 January 2022*
Accepted: *10 March 2022*
Published: *11 April 2022*

Citation:
Li GL, Jin CF, Zhao B and Wu B (2022) Smartphone Use, Technology Affordance for Healthcare and Elders' Life Satisfaction. Front. Public Health 10:861897. doi: 10.3389/fpubh.2022.861897

INTRODUCTION

During the past decade, information and communication technologies (ICTs) such as smartphones, tablets, and laptops have rapidly penetrated into people's daily life (1–6). ICTs affect the well-being of both individuals and the collective society (7). The aging of the earth's population means that more and more elderly people will be using these new technologies to maintain their health and well-being (4).

Life satisfaction is regarded as the essential form of perceived well-being, and previous studies have focused on the relationship between smartphone use and the life satisfaction of the elderly. Some scholars see a positive effect, and believe that older adults can use smartphones to promote life satisfaction in a variety of positive ways, including expanding their social network (8, 9), obtaining social support (10, 11), reducing loneliness (4, 12), collecting health information or monitoring data (13, 14), and enjoying entertainment (4, 15). Specially, in contrast to call and messenger functions, the Apps embedded in smartphones meet with the diversified needs and demands precisely, which influence the elderly's health and well-being a lot (16). Other researchers see some negative effects, including increasing social isolation, smartphone addiction, and internet deception (17–19). These inconsistent findings may result because older people are seen as passive technology recipients, or because we are ignoring the increasing complexity, interactivity, and feasibility of smartphone-based Apps. Thus, further study is necessary to determine how ICTs (particularly smartphones) can be used to increase the life satisfaction of the elderly.

Although it can be difficult to understand why a specific ICT may provide different utility for different individuals, the actors' role is one of the vital explanations (20, 21). That means the personal subjective perception of technology usage may come into play. The concept of technology affordance—the perceived possibilities (or benefits) that are available from the technology—provides a lens to understand how ICTs can provide for a better life for the elderly (22). However, existing studies typically focus on either (a) technology affordance in terms of people using an ICT (such as a smartphone) to achieve a specific goal (23–25), or (b) product design issues (26–28). Less attention has been paid to understand the mechanism by which technology affordance leads to outcomes (22). Moreover, many studies regard personal technological experience as an important personal variable to explain ICT use, and suggest that various psychological and social reasons explain why older adults adopt new technologies to improve their well-being (29–33). As we know, the major challenge to successful aging is the capability to preserve health or avoiding disease through living autonomously, even if they need much help from other people or technologies (34). In other words, the confirmation of the technology affordance for healthcare including physical and mental assistances in future can offer the elderly more confidence to live well. Due to the booming market of mobile Apps, linked to a plenty of devices, tools and service for physical and mental care, the elderly have more and more opportunities to choose the suitable care styles for them. Thus, technology affordance for healthcare is perceived as a way to see new applications and possibilities in using smartphones to help people age well.

The study reported here uses the framework of selective optimization with compensation theory (SOC) to examine the mediating effect of technology affordance between smartphone use and life satisfaction of the elderly. We also explore the moderating effect of living arrangements between smartphone use and technology affordance for healthcare. This study theoretically and empirically advances our current understanding of gerontechnology usage for aging well from a perspective of subjective activity of the elderly. This study makes three unique contributions to extant literature. First, based on SOC, we identify two pathways by which smartphones affect the life satisfaction of the elderly. In the aging process, the life goals of the elderly are bound to vary compared with those of younger people because of changes in living conditions (e.g., retirement, loss of spouse, and residence in an assisted living facility) and because of a decline of physical and psychological functions (3). In old age, social relationships and the maintenance of functions are regarded as two of the most important life goals, which means staying as happy and healthy as possible. These goals produce two kinds of "selections"—elective selections and loss-based selections (35–37). The differences between such goal-oriented selections lead to different technology searching and application mechanisms for the elderly. The SOC model offers a holistic approach that systematically considers processes rather than specific activities and/or wellbeing outcomes. No previous research has explicitly explored how the present and future usage of various smartphone applications supports SOC processes in later life (38). This study is a first step in filling in that gap.

Second, we investigate the mediating effect of technology affordance for healthcare between smartphone use and elderly life satisfaction. Existing studies separately discuss the application of specific mobile phones in promoting well-being in later life (39, 40). In this study, we break down technology affordance for healthcare into two areas: emotional affordance and functional affordance, which is consistent with elective selections and loss-based selections in the SOC model, and explore the "black box" of SOC with empirical evidence in the context of smart aging in China.

Third, we explore the moderating effect of living arrangements in the context of China. In contrast to the emphasis on individualism in western countries, strong family ties are important in the Chinese filial piety culture (41). We therefore investigate whether living with adult children (or not living with adult children) influences how different smartphone applications may be used to deepen our understanding of social support for technology adoption in old age.

THEORY AND HYPOTHESES

Smartphone Use, Emotional Affordance, and Elders' Life Satisfaction

Over the past few decades, a significant volume of research has focused on the question of how to age well (35, 36, 42–44). Selective optimization with compensation theory (SOC), originally put forward by Baltes and Baltes (45), is considered as a classic explanation for harnessing people's subjective initiative to live well in later life (37, 38). SOC states that active aging is achieved by using available resources to select targeted life goals, optimizing lifestyles, and adopting alternative approaches to compensate for physical or mental deficiencies (35, 36, 46). Selection refers to the goal-oriented prioritization for activities. It is classified into elective selection (choosing the more important activities and avoiding the less important activities), and loss-based selection (seeking substitutes to compensate for some lack of functionality). Optimization involves acquiring and applying resources or using new technologies for chosen domains, while compensation means finding alternative approaches to meet the essential needs after loss (35, 36, 45, 47).

With the rapid development of science and technology, some researchers are paying attention to how ICTs—which are an important part of an individual's resources—promote aging well during the process of selective optimization with compensation (11, 15, 44, 48). In particular, smartphones can be used for elective selection and optimization for maintaining physical and mental satisfaction, as well as loss-based selection of smart elderly care devices which are functional compensation for living healthy enough. That means that people have more opportunities to select what style of life they want to live in the later stage of life, and they pursue new technologies for both instrumental and social purposes (10). Under the SOC framework, some studies

have focused on integrating ICTs into SOC strategies, such as the reduced selection of mobile Apps to meet necessities (15, 49), and increased possibilities for learning to optimize spiritual usage of smartphones (50, 51).

Seniors may crave social support and emotional pleasure first (38). Compared with younger people, the elderly are more likely to regard smartphones as the "buffer" of social isolation through online communication with social ties (3, 52). With more leisure time, older people may need more social activities to maintain social relationships, which reduces depression and loneliness, and increases happiness and satisfaction (3, 12, 13, 42, 53, 54). The current generation of seniors can use smartphone-based Apps to embrace the cyber-culture and enhance their quality of life (55).

Affordance theory (56) originally defined affordance as "possibilities of action" which are provided to individuals by their environment. More recently, the term "technology affordance" has appeared in the IS field; it refers to the opportunities for action provided to a user by ICTs (57, 58). A survey conducted by Barnard et al. (59) found that people with a mean age of 68 believed that technology could be mastered by the elderly, even if they could not do it quite yet, for they had the motivations to pursue proper healthcare. Thus, elderly people perceived that technology affordance for healthcare would give them a greater chance to live well later in life. As suggested by Hutchby (60), Markus and Silver (61), Mesgari and Faraj (62), and Wang et al. (63), technology affordance for smartphones can be classified into two areas. Emotional affordance refers to the emotional or social relationships among actors that are realized by technologies, while functional affordance reflects the possibilities for actions provided to users by the technical features. In summary, the two dimensions of technology affordance correspond to appeals of mental health and physical health. For example, people perceive that an SNS linked to a smartphone affords distinct possibilities for action by satisfying the need for convergence with others within a certain scope (64). They also perceive that robotic technologies, smart speakers, and TV multitasking—which are controlled by smartphones—are an emotional affordance which enriches their spare time and promotes life satisfaction (28, 65). A study conducted by Chan (40), found a positive correlation between social affordance (mobile voice communication) and well-being.

In China, many older migrants, who moved to other communities due to the withdrawal or merger of their original rural villages, and trailing parents, who migrated with adult children in their later years, are more likely to use smartphones to promote social integration and life satisfaction (8, 9, 66). WeChat, Tik Tok, Meitu, and other new smart apps encourage empty-nesters and left-behind elderly to show themselves, express comments, and expand their social networks to improve their ego integrity and life satisfaction (9). Based on the foregoing, we propose the following hypothesis:

Hypothesis 1: Emotional affordance can mediate the impact of smartphone use on elders' life satisfaction.

Smartphone Use, Functional Affordance, and Elders' Life Satisfaction

In recent years, the smartphone has become the most popular ICT in the world, and this has attracted attention from researchers who want to know if it improves people's lives (4, 15, 16, 55, 67, 68). Previous studies differentiated smartphone Apps based on communicative patterns vs. non-communicative patterns. The former refers to channels, activities, or engagement that maintain interactions, enhance connections among people, and generate positive feelings. By contrast, non-communicative/passive patterns emphasize communication tools without communicative purpose; these may cause stress, negative emotions, and compulsive problems in adults (3, 17, 63, 69, 70).

The relationship between smartphone use and life satisfaction may vary with age (3, 4). Some research supports an overwhelmingly positive view of smartphone technology as it affects the elderly (4, 71). Researchers found that older people could use smartphones for purposes like taking advantage of the convenience by e-payment, e-bank, and other e-commerce (4, 72), and staying healthy by managed care applications (73, 74). Other studies that focused on elderly people with disabilities (75), dementia (76), or chronic diseases (77), discussed care technology's potential for alleviating pain or compensating for life inconveniences. Those theoretically derived conclusions are largely confirmed by empirical studies (11).

According to SOC theory, although people decline or lose physical and mental functions with age, they still have the possibility of recovery and development (35, 37, 47, 78). To improve the adaptability while aging, the elderly can allocate and use internal and external resources based on goal-oriented personal development to raise their own functionality to a higher level (36–38, 46). Furthermore, the elderly, to a great degree, tend to compensate for their losses by maintaining an existing state rather than striving for best (37). Assisting technologies are a form of resources that are embedded into social networks. They focus on helping, rather than maximizing the utilization of resources (38). Overall, appropriate compensation strategies result in improved life satisfaction (79).

The functional affordance for healthcare of smartphones for the elderly refers to products or systems integrated by information and communication technologies that improve older people's security (especially fall prevention), daily living and health management. These include human activity monitors, health management systems, smart rehabilitation devices, smart mobility aids, and so on (44, 80, 81). Such functions play an important role of aging in place, and help older adults to maintain independence and autonomy as much as possible and feel more satisfied with life, especially after their physical and mental decline becomes noticeable (15, 64, 82–86). Buck et al. (87) noted the benefits of using gerontechnology, especially the use of help Apps, which improve satisfaction with life for older adults. Lizio et al. (88) compared smart tools for daily telemonitoring at home with health medical equipment near

home in the Italian Smart Aging program. They found that most of the elderly subjects preferred smart home programs to improve their quality of life. In other words, the elderly can enhance their independence and autonomy by using intelligent assistive technologies. They can thereby overcome their fear of not being able to take care of themselves and increase their satisfaction of life controllability.

The functional affordance of smartphones has had a strong impact on people's cognitive competence, which raises awareness of ICTs usage and is judged to be the most adequate in reaching the elderly population regarding all issues relating to the incorporation of new technologies in their daily lives (15). den Haan et al. (89) addressed new technology learning and adoption, depending on people's previous technology experience and context. The elderly with good functional affordance of smartphones were more likely to search for, and accept, other gerontechnologies for assistance in compensating for their functional losses (43, 68). A survey by Hernández-Encuentra et al. (15) found that the elderly used ICTs (including smartphones) mainly for leisure (learning, surfing the Internet, travel reservations, etc.), and they would be willing to expand their usage to facilitate daily life-related health and safety issues at home (e.g., telemedicine and tele-assistance, alarm sensors etc.). It seems likely that older adults who do not use smartphones will fall behind in taking advantage of health-related tools; this could lead to decreases in quality of life and jeopardize aspects of their health (71).

We therefore propose the following hypothesis:

Hypothesis 2: Functional affordance can mediate the impact of smartphone use on elders' satisfaction.

The Moderating Effect of Living Arrangement

The details of affordance actualization are contingent on the technology context, which may result in a variety of mechanisms acting as conditions that enable or constrain the actualization of affordance and produce indeterminate outcomes (22). In essence, technology affordance may be a function that is perceived to be provided by existing or future technology, or that is required without knowing whether/when the technology would offer it. That means different affordances may be related to diverse perceptual and attitudinal factors (40), which can be influenced by the people in the system. Specifically, Lawton (90) indicates that living arrangements—an important environmental factor—could act as a resource demanded by individuals which can significantly influence their lifestyle and cognitive functions.

Research on the relationship between living arrangements and cognition or sensibility of the elderly is mixed. Some authors believe that living with adult children is conducive and beneficial to the cognitive function of the elderly (91, 92). Other studies have shown that living with adult children may lead to less free time because of the need to take care of grandchildren and to do household duties; these may have an adverse impact on cognitive function of the elderly (93, 94).

Some studies have found that elderly people living alone may not get enough support from their children, and that may worsen their psychological and cognitive health. Other studies show that older people living alone may have a lower risk of cognitive impairment than with their families, because they must focus on taking care of themselves and completing housework (95). The conclusions vary depending on special context, such as economic and cultural status. For example, Mazzuco et al. (96) compared European countries and found that the relationship between living arrangements and cognitive decline in older people were significantly different in Southern and Northern Europe. Specifically speaking, living with others was more beneficial than living alone in Northern European countries and in some Central European countries, while it was opposite in Southern European countries.

The degree of smartphone usage among older adults also varies by living arrangements. Older people may feel that it is difficult to master multiple applications because of the frequent updating of function integration on smartphones (4, 15). However, learning experiences regarded as self-regulatory processes or life management strategies in SOC theory can overcome the fear of facing new technologies (47). Previous research indicated that older people's learning condition of technology could provide confirmation of their capacity to move on, which meant that there was a positive effect on senior technology affordances (30, 41, 97). In other words, they might voluntarily pursue and operate new kinds of technologies if they were not forced to do so (87, 98). Living with adult children would likely mean more opportunities for enhancing the technology affordance of smartphones *via* the technical supported that is provided by their adult children (e.g., providing hardware, basic information, and technical support) (41).

Changes in economic development and urbanized living arrangements have implications for China's elderly, but there are conflicting patterns. On the one hand, there is an increasing trend of older adults living with their spouse only or living alone rather than living with their children (99). On the other hand, since the family is a vital unit in Chinese culture, many older people have left their own home to live with their adult children. As they take care of their grandchildren, they may come to see that their life could be made happier and more rewarding by the use of a smartphone. Fang et al. (11) suggested that ICT use predicted better well-being among the people 75 old and above. Thus, there may be different priorities for living, depending on whether older people live alone or with their adult children. This may generate different affordances with respect to smartphones (100). We therefore propose the following hypotheses:

Hypothesis 3a: Living with adult children will positively moderate the relationship between smartphone use and emotional affordance.

Hypothesis 3b: Living with adult children will positively moderate the relationship between smartphone use and functional affordance.

Based on all of the above hypotheses, we propose the model in **Figure 1**.

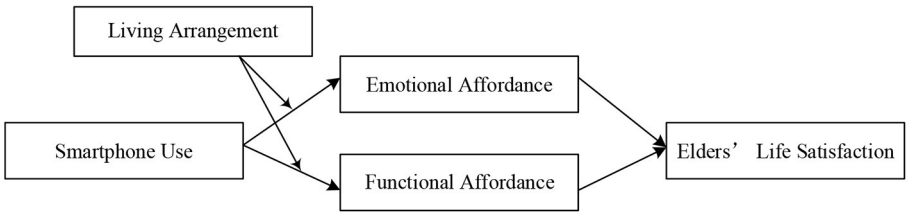


FIGURE 1 | Conception model.

MATERIALS AND METHODS

Data and Sample

We collected data from Zhejiang Province, since it is one of the earliest provinces to enter the "aging society," and since the degree of aging in that province ranks among the top level in China (101). Zhejiang is also one of the most economically developed provinces, is famous for its digital economy, and has promoted the smart care industry to a leading national position (102, 103).

The data are from a survey questionnaire developed by Zhejiang University of technology and Zhijiang laboratory, a research institute established jointly by Zhejiang Provincial Government, Zhejiang University and Alibaba Group. In China, smart elder-care devices are promoted to communities and families due to government pressure. Pilot communities of smart care from 11 cities in Zhejiang Province were randomly selected for this survey. All investigators had received professional training and were required to carry out one-to-one online questionnaire item explanations for the interviewed elderly respondents to prevent misunderstanding.

Table 1 shows the demographic characteristics of individuals in our sample.

TABLE 1 | Description of sample.

Gender		
Male	470	49.9%
Female	471	50.1%
Age		
60–69	443	47.1%
70–79	366	38.9%
≥80	132	14.0%
Education background		
Illiteracy	186	19.8%
Primary below	226	24.0%
Primary school	207	22.0%
Middle school or Junior college	289	30.7%
Bachelor or above degree	33	3.5%
Place of residence		
Rural areas	412	43.8%
Urban areas	529	56.2%
Marital status		
Married	773	82.1%
Unmarried	168	17.9%
Total	941	100%

Measurements

Elders' Life Satisfaction

Referring to previous studies (104, 105), life satisfaction means holding positive emotions rather than negative emotions in general. We use one item which directly evaluates respondent perceptions of the extent to which the elderly have an overall evaluation of life satisfaction. The item is expressed as "All things considered, how satisfied are you with your life as a whole?" This item uses a five-point Likert scale, where 1 = "totally dissatisfied" and 5 = "totally satisfied."

Smartphone Use

Respondents were asked, "Do you use one smartphone at least?" with a response of yes or no. We created a dichotomous variable indicating older adults' smartphone use.

Technology Affordance for Healthcare

The value of affordance arises from the perceived content and the process of the interaction of human and products (27, 106). In ICT context, perceiving useful applications is much more important than figuring out the way to use (22, 24, 25, 58). Therefore, we focus on the dimensions of technology affordance in the application and content perspective. Moreover, across a wide variety of domains embedded in smartphones, Apps related with healthcare play a vital role (34). Thus, following Chan (40), Hutchby (60), Markus and Silver (61), Mesgari and Faraj (62), and Wang et al. (63), we divided technology affordance for healthcare into emotional affordance and functional affordance based on apps linking smartphones. Each term contains possible functions or applications or compatible products and service perceived by the participants. Emotional affordance contains three items including company, entertainment and social support, while functional affordance refers to safety, living assistance and health management. Each item is provided through one question: "Which applications or service linked with your smartphone for X can you perceive in future?" And X is for company or entertainment or social support or safety or living assistance or health management. The response for each item contains four to six options, such as spiritual consolation AI, robots, smart speakers and smart chat rooms for company, and fall prevention monitors, night monitors, environment monitors, one-touch call care devices,

remote keyless access control and positing bracelet for safety. The participants were asked to choose the possible functions and we counted the total options for each term. Due to positive skew, we transformed the total number of devices/apps perceived possible and useful in future into a 5-point ordinal scale in order to achieve normality.

The reflective multi-item constructs, including emotional affordance and functional affordance, were assessed by analyzing factor loadings, Cronbach's alpha (α), composite reliability (CR), and average variance extracted (AVE). The test results are listed in **Table 2**. All factor loadings were positive and significant at $p < 0.01$, supporting unidimensionality of the measures. Cronbach's alphas and composite reliability exceeded the common cut-off levels of 0.7 for all constructs, and the AVE threshold of 0.5 was met in all cases.

Living Arrangement

Since the direct blood relationship is regarded as the most important social relationship in China, and since the adult children play a vital role in elderly technology learning (59, 89, 107), we asked whether participants were living with their adult children as our measure of the variable "living arrangement." "Yes" or "No" was presented as a 1 or 0 dummy variable, respectively.

Control Variables

Participant characteristics might influence their learning capacity and motivation to use a smartphone, and this might relate to life satisfaction. Consistent with the previous literature (3, 32, 41, 66, 100), we controlled demographics including gender, age, educational background, place of residence, and marital status.

Analytical Strategy

According to Baron and Kenny's suggestion, we tested the mediation and moderation effects in the study by using separate hierarchical multiple regression analyses through STATA 17.0. In all equations, the control variables were filed in before the other independent variables to eliminate their effects from the relationships of principal interest. We finally constructed 11 models.

RESULTS

The descriptive statistics and correlation matrix are shown in **Table 3**. The results show that smartphone use is positively associated with emotional affordance and elderly life satisfaction. Life satisfaction of the elderly is positively associated with living arrangement, educational background and marital status, and negatively associated with age and place of residence.

The Mediating Effect of Emotional Affordance Between Smartphone Use and Elders' Life Satisfaction

In **Table 4**, Model 5 only contains the control variables and Model 6 contains results of the main effect of smartphone use on life satisfaction of the elderly. Model 6 shows that there is a positive relationship between smartphone use and life satisfaction of the elderly (coefficient = 0.152, $p < 0.01$) is significant and positive. Models 2, 7, and 8 examine the mediation effect of use of emotional affordance between smartphone use and life satisfaction of the elderly. Model 2 predicts smartphone use has a positive impact on emotional affordance (coefficient = 0.831, $p < 0.01$). Model 7 shows that emotional affordance is significantly and positively related to life satisfaction of the elderly (coefficient = 0.107, $p < 0.01$). Model 8 indicates that

TABLE 2 | Multi-item measurement information.

Construct	# of items	Range of loading	Cronbach α	CR	AVE
Emotional affordance	3	0.815–0.897	0.824	0.892	0.734
Functional affordance	3	0.749–0.823	0.789	0.8378	0.633

TABLE 3 | Descriptive statistics and correlation.

Variable	*N*	Mean	SD	1	2	3	4	5	6	7	8	9	10
Life satisfaction of the elderly	941	3.64	0.79	1									
Smartphone use	941	0.51	0.50	0.22*	1								
Emotional affordance	941	1.58	0.88	0.08*	0.51*	1							
Functional affordance	941	1.69	1.16	0.01	0.21*	0.46*	1						
Living arrangement	941	0.38	0.48	0.08*	−0.01	0.01	−0.09*	1					
Gender	941	0.50	0.50	0.03	0.13*	0.01	0.01	−0.07*	1				
Age	941	4.25	0.10	−0.16*	−0.41*	−0.21*	−0.02	−0.14*	0.00	1			
Place of residence	941	0.44	0.50	−0.10*	−0.20*	−0.16*	−0.20*	0.05	−0.03	0.04	1		
Education background	941	2.74	1.19	0.10*	0.41*	0.29*	0.24*	−0.05	0.34*	−0.16*	−0.27*	1	
Marital status	941	0.82	0.38	0.21*	0.26*	0.11*	0.07*	−0.11*	0.19*	−0.32*	0.02	0.21*	1

*$p < 0.05$.

TABLE 4 | The hierarchical regression results including mediating effect of emotional affordance.

	Emotional affordance					Life satisfaction of the elderly					
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**	**Model 9**	**Model 10**	**Model 11**
Control variable											
Gender	−0.138**	−0.155***	−0.153***	−0.153***	−0.025	−0.028	−0.010	−0.014	−0.025	−0.025	−0.012
	(−2.348)	(−2.891)	(−2.860)	(−2.861)	(−0.462)	(−0.520)	(−0.188)	(−0.259)	(−0.468)	(−0.468)	(−0.217)
Age	−1.475***	−0.187	−0.102	−0.116	−0.500*	−0.264	−0.343	−0.247	−0.127	−0.117	−0.107
	(−5.243)	(−0.688)	(−0.371)	(−0.418)	(−1.952)	(−0.972)	(−1.328)	(−0.913)	(−0.461)	(−0.425)	(−0.390)
Place of residence	−0.164***	−0.083	−0.086	−0.089*	−0.174***	−0.159***	−0.156***	−0.151***	−0.163***	−0.161***	−0.153***
	(−2.864)	(−1.576)	(−1.632)	(−1.697)	(−3.319)	(−3.022)	(−2.989)	(−2.887)	(−3.120)	(−3.067)	(−2.924)
Education background	0.198***	0.095***	0.094***	0.093***	0.025	0.006	0.004	−0.002	0.006	0.006	−0.002
	(7.637)	(3.824)	(3.815)	(3.760)	(1.060)	(0.244)	(0.163)	(−0.101)	(0.224)	(0.263)	(−0.066)
Marital status	0.072	−0.019	−0.002	−0.006	0.302***	0.285***	0.294***	0.287***	0.313***	0.316***	0.317***
	(0.933)	(−0.271)	(−0.025)	(−0.078)	(4.269)	(4.026)	(4.184)	(4.065)	(4.391)	(4.426)	(4.447)
Independent variable											
SU		0.831***	0.833***	0.833***		0.152***		0.077	0.156***	0.156***	0.083
		(14.089)	(14.138)	(14.148)		(2.587)		(1.199)	(2.660)	(2.657)	(1.292)
Mediator variable											
EA							0.107***	0.090***			0.087***
							(3.600)	(2.768)			(2.679)
Moderator variable											
LA			0.087*	0.086*					0.140***	0.141***	0.134**
			(1.666)	(1.648)					(2.707)	(2.720)	(2.581)
Interaction terms											
SU×LA				0.137						−0.100	−0.112
				(1.345)						(−0.988)	(−1.108)
_cons	7.442***	1.873	1.465	1.529	5.564***	4.542***	4.771***	4.373***	3.881***	3.834***	3.701***
	(6.073)	(1.585)	(1.215)	(1.268)	(4.985)	(3.846)	(4.219)	(3.712)	(3.229)	(3.187)	(3.084)
N	941	941	941	941	941	941	941	941	941	941	941
R-square	0.134	0.286	0.288	0.289	0.051	0.057	0.064	0.065	0.065	0.066	0.073

SU, smartphone use; EA, emotional affordance; LA, living arrangement.
**p < 0.10, **p < 0.05, and ***p < 0.01.*

smartphone use is not significant, while emotional affordance is significantly and positively associated with life satisfaction of the elderly (coefficient = 0.090, $p < 0.01$). These results support H1, which means that emotional affordance mediates a positive relationship between smartphone use and life satisfaction of the elderly.

The Mediating Effect of Functional Affordance Between Smartphone Use and Elders' Life Satisfaction

In **Table 5**, Model 5 only contains the control variables and Model 6 contains results of the main effect of smartphone use on life satisfaction of the elderly. Model 6 shows that there is a positive relationship between smartphone use and life satisfaction of the elderly (coefficient = 0.152, $p < 0.01$) is significant and positive. Models 2, 7, and 8 in **Table 5** examine the mediation effect of functional affordance. Model 2 predicts that smartphones will have a positive impact on use of functional affordance (coefficient = 0.391, $p < 0.01$). Model 7 shows that functional affordance is significantly and positively related to the elderly life satisfaction (coefficient = 0.120, $p < 0.01$). Model 8 indicates that smartphone use is positive related to the elderly life satisfaction (coefficient = 0.108, $p < 0.1$), while functional affordance is significantly and positively associated with the elderly life satisfaction (coefficient = 0.114, $p < 0.01$). In all, these results support H2, which means functional affordance mediates the positive relationship between smartphone use and the elderly life satisfaction.

The Moderating Effect of Living Arrangement Between Smartphone Use and Emotional Affordance

Refer back to **Table 4**, which shows the results of testing H3 (predicting positive moderation of living arrangement between smartphone use and emotional affordance). Models 4 and 11 in **Table 4** contain the interaction terms around which the hypotheses were offered. The results of them both suggest that the interactive effect of smartphone use and living arrangement on emotional affordance is not significant. Hence, the results do not support H3a that living with adult children strengthens the positive relationship between smartphone use and emotional affordance.

The Moderating Effect of Living Arrangement Between Smartphone Use and Functional Affordance

Table 5 also reports the results for H3b which predicts a positive moderation of living arrangement between smartphone use and functional affordance. Models 4 and Model 11 contain the interaction terms around which the hypotheses were offered. Although Model 11 shows that the interaction term is not significant after adding all variables, the results of Model 4 still suggests that the interactive effect of smartphone use and living arrangement on functional affordance is significant and positive (coefficient = 0.298, $p < 0.05$). Thus, H3b is supported.

DISCUSSIONS

Theoretical Contributions

We believe this study makes three contributions to the literature. First, the study distinguishes two different mechanisms to explain how smartphones can promote life satisfaction of the elderly based on elective selection and loss-based selection to improve the subjective well-being of older adults. In terms of social development goals, the emotional affordance of smartphones, which means the possibilities to accept more compatible and prolonged applications or service concerning spiritual pleasure or comfort to improve life satisfaction, old people have more opportunities and choices to accept new technologies by smartphones to enhance social connection and enrich the spirit world. In order to maintain physical and/or mental functions, older people with high functional affordance are willing to learn and accept different types of intelligent care devices to enhance their independence and autonomy; this provides another way to improve their life satisfaction. Previous studies have focused on the qualitative analysis of active aging through technology learning and adoption in the SOC framework, especially discussing specific activities in three processes of SOC (selection, optimization and compensation) separately (77, 83, 108). Since the SOC model offers a holistic approach that systematically considers processes rather than specific activities and/or wellbeing outcomes (38), those two mechanisms in this study have regarded the three processes of SOC as a whole perspective. Thus, starting from the macro level and overall subjective perception, our study contributes to refine SOC theory by quantitative empirical research.

Second, we contribute to the literature by examining the effects of the two different aspects of technology affordance (emotional and functional) in the aging context. Technology affordance exists independently on users and works only if the user perceives and actualizes it (22). So the interactions between technology and users who have unique goals, usage context must be taken into account (57, 58, 61). We therefore classify technology affordance in terms of the perceived possible extensibility of smartphones, rather than in terms of their own attributes (structure, utility, communication, etc.). Our results show that both emotional affordance and functional affordance mediate the relationship between smartphone use and the life satisfaction of the elderly; this provides empirical evidence of technology affordance theory.

Third, we examine the moderating effects of living arrangements on the different types of technology affordance when the elderly use smartphones. These results suggest that smartphone use may broaden functional affordance by strengthening learning capabilities and experiences when the elderly live with adult children. This is consistent with previous studies showing that the internet usage of older adults expanded as a result of encouragement from their children (109, 110). However, we also found that the moderating effect of living arrangements between smartphone use and emotional affordance was not significant. One reason may be that the actualized functions of emotional affordance are less complex than those of functional affordance. For example, irrespective

TABLE 5 | The hierarchical regression results including mediating effect of functional affordance.

	Functional affordance					Life satisfaction of the elderly					
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**	**Model 9**	**Model 10**	**Model 11**
Control variable											
Gender	−0.178**	−0.186**	−0.186**	−0.186**	−0.025	−0.028	−0.003	−0.007	−0.025	−0.025	−0.003
	(−2.261)	(−2.383)	(−2.378)	(−2.382)	(−0.462)	(−0.520)	(−0.064)	(−0.124)	(−0.468)	(−0.468)	(−0.065)
Age	0.217	0.822**	0.834**	0.805**	−0.500*	−0.264	−0.526**	−0.358	−0.127	−0.117	−0.210
	(0.575)	(2.079)	(2.071)	(2.002)	(−1.952)	(−0.972)	(−2.085)	(−1.333)	(−0.461)	(−0.425)	(−0.773)
Place of residence	−0.373***	−0.335***	−0.335***	−0.343***	−0.174***	−0.159***	−0.129**	−0.120**	−0.163***	−0.161***	−0.121**
	(−4.861)	(−4.380)	(−4.380)	(−4.481)	(−3.319)	(−3.022)	(−2.467)	(−2.301)	(−3.120)	(−3.067)	(−2.316)
Education background	0.230***	0.181***	0.181***	0.178***	0.025	0.006	−0.003	−0.015	0.006	0.006	−0.014
	(6.607)	(5.018)	(5.014)	(4.939)	(1.060)	(0.244)	(−0.106)	(−0.592)	(0.224)	(0.263)	(−0.574)
Marital status	0.208**	0.165	0.168	0.159	0.302***	0.285***	0.277***	0.266***	0.313***	0.316***	0.298***
	(2.004)	(1.600)	(1.605)	(1.528)	(4.269)	(4.026)	(3.966)	(3.806)	(4.391)	(4.426)	(4.221)
Independent variable											
SU		0.391***	0.391***	0.391***		0.152***		0.108*	0.156***	0.156***	0.111*
		(4.546)	(4.546)	(4.559)		(2.587)		(1.834)	(2.660)	(2.657)	(1.890)
Mediator variable											
FA							0.120***	0.114***			0.116***
							(5.483)	(5.160)			(5.242)
Moderator variable											
LA			0.012	0.010					0.140***	0.141***	0.140***
			(0.159)	(0.131)					(2.707)	(2.720)	(2.736)
Interaction terms											
SU×LA				0.298**						−0.100	−0.135
				(2.003)						(−0.988)	(−1.343)
_cons	0.315	−2.304	−2.361	−2.220	5.564***	4.542***	5.526***	4.805***	3.881***	3.834***	4.091***
	(0.192)	(−1.338)	(−1.342)	(−1.263)	(4.985)	(3.846)	(5.027)	(4.121)	(3.229)	(3.187)	(3.446)
N	941	941	941	941	941	941	941	941	941	941	941
R–square	0.098	0.118	0.118	0.121	0.051	0.057	0.080	0.084	0.065	0.066	0.093

SU, smartphone use; FA, functional affordance; LA, living arrangement.
**p < 0.10, **p < 0.05, and ***p < 0.01.*

of living arrangements, the elderly always need communication affordance from smartphones (63, 111–113). Moreover, on the one hand, the social needs of the elderly may be diluted by family happiness. On the other hand, dealing with much more housework or taking care of grandchildren encroaches on the time for the elderly to expand their social ties.

Practical Implications

There are several practical implications of our study. Firstly, the elderly can benefit by accepting the concept of active aging and giving full play to their subjective initiative to use smartphones and related gerontechnologies because more and more mobile applications are linked to intelligent care devices. They would have more chances to obtain the healthcare resource though technology affordance. Meanwhile, this will require that elderly people improve their knowledge about smartphones and their applications. It's never too late to start learning something new, even in the late period of life (59, 114). This improved digital literacy will allow older people to more easily access intelligent care resources. Secondly, the spread of cross-technologies creates opportunities for producers to better serve the elderly. It is necessary to commit to the accurate supply of demand-oriented smart elderly care services for the elderly. Producers should also think about how new technologies can effectively connect with the technologies that the elderly already know. This would create another market for suitable products, and would increase the life satisfaction of the elderly. For example, one-touch call care devices should be targeted at the oldest-old people, while compatible apps should be promoted to younger older people with smartphones. Finally, the government should not only take the lead in launching intelligent care equipment, but also push to create a stronger digital technology learning environment, especially encouraging the family to help the elderly improve their digital literacy. Due to the decreased small number of children in one family and the aggravation of social pension burden, it is imperative to consider appropriate public policies to the combine family support for the elderly and smart aging functions.

LIMITATIONS AND FUTURE RESEARCH

We recognize that there are several limitations in this study. First, the geographical limitation of data collection may affect the generality of research conclusions. Although Zhejiang Province plays an essential role in digital aging in China, we should not ignore the variations in this issue between regions with different degrees of economic backwardness and aging. Future research is necessary with samples from various regions to increase the generalizability of the results. Due to cultural heterogeneity, future research is also needed to examine the cross-national generalizability of our results. Second, this study focusses only on living arrangements in the context of cross-technology affordance. Future research should analyze digital aging from an integrated perspective, such as taking living arrangements with age together (41). In addition, urbanization and family planning policies have created new social problems for the elderly in China, which may produce more sub-themes based on the social networks of the elderly. Finally, a cross-sectional survey may cause a biased interpretation among variables. Therefore, further studies should attempt to address this issue.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

Ethical review and approval were not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

BW contributed to conception, design of the study, and participated the refining of the manuscript. GL wrote the first draft of the manuscript and was responsible for following revision. BZ organized the database and wrote the section of theoretical part. CJ performed the statistical analysis. All authors contributed to manuscript revision, read, and approved the submitted version.

FUNDING

This research was funded by Major Project of Zhejiang Provincial Philosophy and Social Sciences Research Planning Project, grant No. 20YSXK02ZD; the Planning Program for Science and Technology of Zhejiang Province of China, grant No. 2021C35024; and Major Fund of National Philosophy and Social Science of China, grant No.17ZDA088.

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frontiers | Frontiers in Public Health

ORIGINAL RESEARCH
published: 13 April 2022
doi: 10.3389/fpubh.2022.862384

A Disease Pathway Framework for Pain Point Identification and Elaboration of Product Requirements Across Patient Care Plan Using Innovation Think Tank Global Infrastructure

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OPEN ACCESS

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Reviewed by:
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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *25 January 2022*
Accepted: *21 March 2022*
Published: *13 April 2022*

Citation:
Haider S, Goenka A, Mahmeen M, Sunny S, Phan T, Mehdi SA, Hassan DM and Weber E (2022) A Disease Pathway Framework for Pain Point Identification and Elaboration of Product Requirements Across Patient Care Plan Using Innovation Think Tank Global Infrastructure. Front. Public Health 10:862384. doi: 10.3389/fpubh.2022.862384

Healthcare providers as well as medical technologists lay a strong focus on clinical conditions for patient centric care delivery. Currently, the challenges are to (1) obtain a consolidated view of various stakeholders and pain points for the entire disease lifecycle, (2) identify interdependencies between different stages of the disease, and (3) prioritize solutions based on customer needs. A structured approach is required to address clinical needs across disease care plans tailored to different geographies and ethnicities. Innovation Think Tank (ITT) teams across multiple locations formed focus groups to elaborate the pathways of 22 global diseases, selected based on ranking of associated economic burden and threat to life. Ideation sessions were held to identify pain points and find innovative solutions. Additionally, inputs were taken from co-creation sessions at universities worldwide. The optimization and design of infographics and care plan was done based on the key information gathered—facts and figures, stakeholders, pain points and solutions. Finally, validation was obtained from clinical and technology experts globally. A disease pathway framework was created to develop pathways for 22 global diseases. Over 1,500 pain points were collected and about 1,900 ideas were proposed. The approach was applied to optimize its application to 30 product and portfolio definition projects over 2 years at Siemens Healthineers, as well as co-creation programs with universities and hospitals. The disease pathway framework provides a unique foundation for extensive collaboration among multiple stakeholders, through information sharing and delivering high-quality solutions based on the identified problems and customer needs.

Keywords: disease pathways, Innovation Think Tank, care plans, chronic disease management, disease statistics, healthcare system

INTRODUCTION

The Global Burden of Disease study addresses the changing healthcare needs of the global population from 1990 to 2020. It is estimated that as the population ages, the disease burden will shift from communicable diseases to non-communicable diseases (NCDs) and injuries, and most deaths and disabilities will be due to the latter (1). Fifty percent of the world's population does not have access to basic health services. Due to rising healthcare expenditure, millions of people are pushed into extreme poverty (2). Chronic diseases may result in increased treatment costs due to presence of comorbidities, readmissions, diagnostic and medication expenses. It may also cause decreased productivity due to disability. Moreover, increasing disease burden can lead to delayed diagnosis, inappropriate treatment, and increase in mortality and morbidity. Disease burden could be categorized by various health-related indicators like mortality indicators, morbidity indicators, disability rates, and socio-economic indicators (3, 4). It is critical to understand why individuals die since mortality data (**Figure 1**) can help us evaluate the efficiency of our health systems and allocate appropriate resources to different sectors, responding to varying epidemiological situations effectively (5, 6).

According to a World Health Organization (WHO) report, of the 55.4 million deaths worldwide in 2019, 55% were due to the ten leading causes of death. NCDs were responsible for 74% of deaths worldwide in 2019. The worldwide economic burden of NCDs is projected to be around $47 trillion from 2010 to 2030 (7). Cardiovascular diseases (CVDs) are the leading cause of premature deaths and growing healthcare expenditure which accounts for nearly 50% of the economic disease burden (8). Due to exponential population growth, aging population and changing prevalence of risk factors, the burden of cancer is increasing worldwide (19.3 million new cases and 10 million deaths in 2020) (9). The economic loss from cancer related disability and death worldwide was $895 billion in 2008 (10). In the US, $246 billion is projected to be spent on cancer care in 2030 (11). Morbidity, mortality and disability due to neurological diseases, chronic respiratory diseases, chronic kidney disease (CKD) and diabetes are also on the rise (12–16). In the US alone, neurological disorders contributed to an economic burden of $800 billion in 2014 (17). In 2019, healthcare cost due to chronic respiratory diseases (CRDs) in the EU region alone was 380 billion Euros (14, 15). 6.7 million died and US$ 966 billion was the healthcare spending due to diabetes or its complications in 2021. It is estimated to reach US$ 1 trillion by 2030 (16). Ischemic heart disease (IHD), stroke, and chronic obstructive pulmonary disease (COPD) accounted for 16, 11, and 6% of global deaths, respectively, in 2019 (18). There has been an overall decrease in the burden of communicable diseases (CDs), evident from the fall in the incidence and deaths due to tuberculosis and HIV over the years (19, 20). Apart from NCDs and CDs, injuries are also responsible for many deaths globally. According to the WHO "Global status report on road safety 2018," road traffic crashes result in 1.35 million annual deaths (21).

Global chronic disease burden is remarkable, and the conventional methods for healthcare delivery are unsuitable to address the current needs. In the complex chronic disease healthcare environment, we have different stakeholders and their interdependencies throughout different stages of the disease (22). Major value providers responsible for care delivery are medical device manufacturers and clinicians. These two stakeholders are interdependent, working to understand the problem, design solutions, and deliver appropriate care to the patient. So, on both sides there is a need to understand the chronic disease management stages to reach, assess and solve the challenges of the patients. Most education about health care during the progression of chronic disease is through the introduction of preventive measures, which are strongly associated with risk factors (23). Though not an illness, risk factors need to be identified and managed in asymptomatic people as it might lead to complications in some individuals later in life (24). It is imperative to focus on health promotion, raise awareness, modify health behaviors, and promote early disease screening to facilitate disease prevention (25, 26). Physical symptoms account for fifty percent of all out-patient visits. Educating individuals about symptoms of a particular disease can contribute to prompt assessment, early intervention, and improved patient outcome (27). Moreover, disease management can be improved by early diagnosis and timely treatment, thereby preventing complications and prolonging patient survival. Patients with chronic disease often require rehabilitation to get back to their daily routine and have a healthy lifestyle. Emphasis is now placed on evidence-based care by rehabilitation clinicians as it is an essential part of patient care (28–30).

From the above literature review, we can conclude that to achieve optimal patient care, we need a structured approach to address clinical needs across disease care plans globally. Looking at the bigger picture, what is required is sustainable innovation ecosystem and technological advancement using structured, dynamic and customer centric frameworks to drive progress in the healthcare system globally. It is challenging to get a consolidated perspective of diverse stakeholders and pain points for the entire disease lifecycle, and to identify interdependencies between different stages of disease. It is also difficult to prioritize solutions as per customer needs. We thus proposed a framework for disease pathways to provide an overall picture of where the difficult points lie in the disease management and to propose solutions for the same. The disease pathway is a novel tool that describes the procedures involved in healthcare delivery throughout the development of various diseases. The framework was applied for 22 diseases: coronary artery disease (CAD), stroke, structural heart disease, peripheral vascular disease (PVD), AD, dementia, PD, multiple sclerosis (MS), depression, lung cancer, breast cancer, liver cancer, oral cancer, leukemia, COPD, CKD, diabetes, TB, HIV, infectious diseases, traumatic injury, and wound healing disorders. With the focus on open innovation in healthcare, the complete disease pathways, comprising pain points, impact of COVID-19 and possible solutions on emerging technologies to address the real-world challenges, have been curated and validated with clinical experts globally.

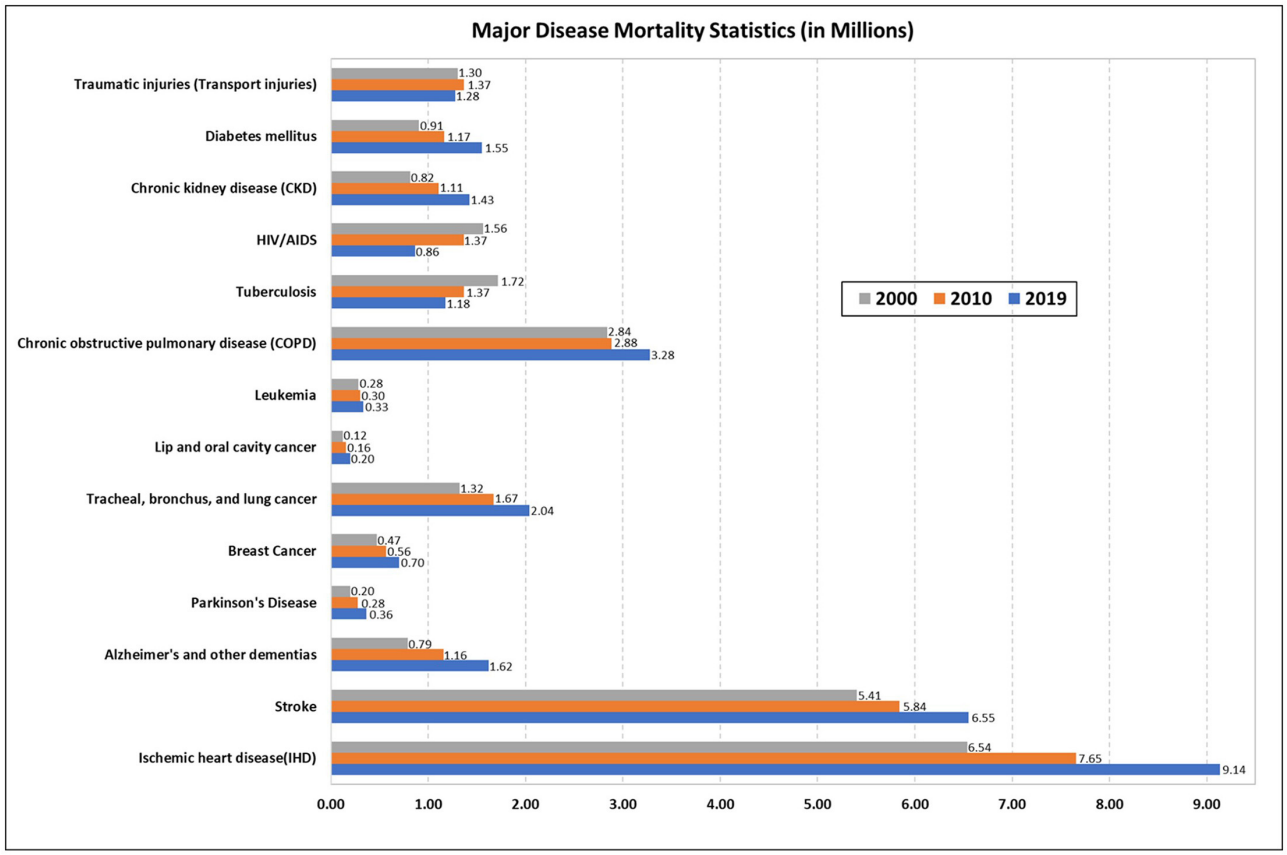


FIGURE 1 | Major disease mortality statistics from 2000, 2010, 2019.

METHODS

With over 16 years of experience, Innovation Think Tank (ITT) teams have developed real-world healthcare models that incorporate observed "best practices" gathered from 900+ global hospital visits, multiple co-creation sessions with clients, and literature reviews. Each hospital department is visualized, and information maps of observed problems, also called "pain points," and best practices are placed at the appropriate location in the model (31, 32). This data provides a valuable basis for visualizing areas where the acquired mission can be identified and workflows that can benefit from an innovative solution or product. ITT introduces different stakeholders and brings them together under the same mandate to create something together. However, it is crucial to note that healthcare facilities differ from the regions in which they are located. Therefore, it is essential to conduct evaluations in regional contexts.

We identified 22 global diseases based on the highest economic burden, social impact, and mortality rate. To create the disease pathway framework, there was a need of a suitable methodology which could cover all qualitative and quantitative aspects. "Sultan Haider in 2005" developed an ITT methodology which contains steps such as acquiring a mandate, identifying the problem, analyzing the root cause, identifying interdependencies, engaging stakeholders, creating the big picture, conceptualizing, and validating with experts, creating decision propositions, and commercializing the solution (31). This methodology was suitable because it addresses the problem, includes all stakeholders. Above steps in ITT methodology follows a mixed approach with qualitative and quantitative aspects. As mentioned, taking the above methodology as a reference, ITT teams around the world formed groups. Disease topics were assigned to each group based on members' skills and areas of interest. 20 co-creation sessions were held within a transdisciplinary team of more than 50 participants composed of medical experts from ITT sites worldwide and ITT's technical and biomedical team to understand the disease, develop the disease care plan, and analyze pain points during the disease life cycle.

Disease clusters were formed, and topics were rotated between groups to gather insights across all disciplines. Ideation sessions were organized for each pain point to identify innovative solutions in the categories of digitization, automation, and clinical innovation while team members swapped roles. Additionally, inputs were taken from co-creation programs at universities in Germany, the United States of America (USA), United Kingdom (UK), India, China, Turkey, United Arab Emirates (UAE), and South Africa. The optimization and design

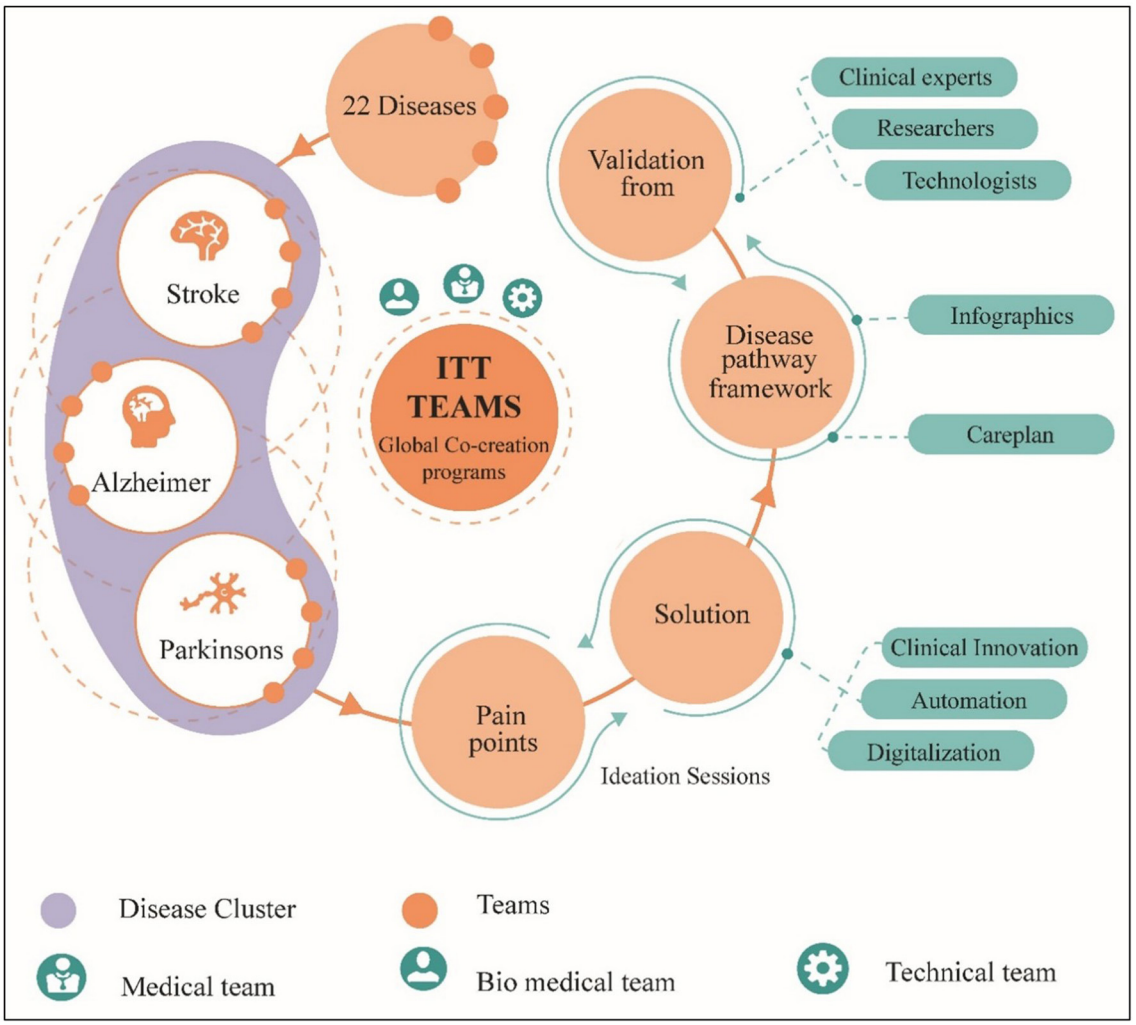


FIGURE 2 | Transdisciplinary methodology to establish disease pathway framework by identifying pain points, proposing solutions, and validating by clinicians.

of the infographic and care plan was done for each disease based on the key information gathered—facts and figures, stakeholders, pain points and associated solutions. Finally, extensive validation of the same was obtained from experts worldwide (**Figure 2**). The ITT co-development and laboratory infrastructure program supported the adaptation of these disease pathways, considering global trends and challenges. In 2020, after the pandemic COVID-19, the disease pathways were adapted to the impact of SARS-CoV-2.

Two significant features of these disease pathways are to showcase impact on global & economic burden and inclusion of stages before the onset of each disease. Health care providers believe that prevention is always better than cure, and therefore disease trajectories are presented in eight stages: prenatal, prevention, symptoms, diagnosis, treatment, rehabilitation, follow-up and out-patient. Looking at the disease trajectories in their entirety enables the creation of requirements for solutions that address the challenges holistically and help stakeholders prevent or halt the progression of the disease.

RESULTS

A disease pathway framework was created to develop disease pathways for 22 global diseases. The proposed framework consists of three core elements as follows: (1) Facts and figures template (2) Disease pathway (3) Technological solution framework.

In this article, we have covered the facts and figures template and the disease pathway. The technological solutions framework is out of the scope of this article. It will be considered in future work to present the disease-centric automation framework. Let us start with the facts and figures template. It is intended to provide a general and consolidated overview of common disease symptoms, followed by statistical figures on major diseases to show current incidence and mortality with their global and economic impact. Given the wealth of experience and impact of COVID-19 on chronic disease management, we have also made provisions to present the impact of community diseases.

TABLE 1 | Disease clusters for the 22 global diseases considered in the study, based on the ICD-10 classification system.

Disease cluster	Diseases
Certain infectious and parasitic diseases	Infectious diseases Tuberculosis Human immunodeficiency virus/acquired immunodeficiency syndrome (HIV/AIDS)
Neoplasms	Lung cancer Breast cancer Liver cancer Oral cancer Leukemia
Endocrine, nutritional, and metabolic diseases	Diabetes
Mental and behavioral disorders	Depression
Diseases of the nervous system	Alzheimer's disease Dementia Parkinson's disease Multiple sclerosis
Diseases of the circulatory system	Stroke Coronary artery disease Structural heart disease Peripheral vascular disease
Diseases of the respiratory system	Chronic obstructive pulmonary disease
Diseases of the genitourinary system	Chronic kidney disease
Injury, poisoning and certain other consequences of external causes	Traumatic injury Wound healing disorder

We divided these selected diseases into clusters based on the International Statistical Classification of Diseases and Related Health Problems - 10 (ICD-10), a universally accepted medical classification system (**Table 1**).

Thereafter, a care plan was framed for every disease at each stage of development. Each care plan stage contains information about the stakeholders involved, the pain points, and the respective solutions. The disease care plan model presented is broadly divided into stages such as:

1. Prenatal: This stage is unique as it covers that portion of the disease life cycle that can occur or exist even before birth. It is important because by focusing on this stage, we can investigate techniques by which pregnant women can reduce the disease risk for their unborn child.
2. Prevention: How an ordinary person can prevent the occurrence of a particular disease is the focus of this section. Measures that can be taken to prevent the disease based on the risk factors have been elaborated in this stage for each disease. It also includes steps to stop the progression of a disease at an early stage to prevent it from getting worse.
3. Symptoms: This section mainly covers the disease's life cycle when the patient begins to feel the physical or psychological effects of the disease. Symptoms may or may not be disease specific. They play an essential role in the progression of the disease, which should never be neglected. The study of symptoms not only provides information on the onset of the disease but also aids in deciding on the course of treatment.
4. Diagnosis: The section of diagnosis mainly deals with identification of the nature of illness or other problems by clinical, laboratory and radiological diagnosis. Early diagnosis of chronic diseases is crucial because early detection leads to better treatment outcomes than intervening at a later stage. Therefore, different types of diagnostic tools and methods have been developed to correctly diagnose and determine the severity and subtype of the disease.
5. Treatment: The treatment section includes the medical or surgical care given to a patient for an illness or injury. As with diagnosis, a variety of existing and advanced therapeutic measures have been found to treat disease.
6. Rehabilitation: Rehabilitation mainly includes the interventions done to bring one back to the daily routine after an illness. It can include routine health monitoring and exercises in gym or sports centers, rehabilitation centers, using fitness equipment, devices, and following health plans.
7. Follow-up: This section comprises of care that the patient receives over a period after treatment completion. Regular medical checkups, clinical examination, laboratory and radiological tests, medication change might be included here.
8. Out-patient: This section includes the patient consultation that does not require overnight stay at the hospital. Patient history taking, physical examination, diagnostic tests, and treatment (medication, day care surgeries) can be included. Patient self-care and management at home is also considered in this section of the care plan.

Thus, proposed disease pathway framework was developed comprising of the infographics which contained the facts and figures for disease, and the care plan which showed the patient journey throughout the disease progression as described above, interdependent stakeholders involved in each stage, their pain points, interdependencies between the stages, and solutions based on customer needs. For each disease, the information collected was consolidated into disease pathway framework template, including infographics and care plan stages. The care plan model described in **Figures 3**, **4** is the skeletal form of the disease pathway framework, where user can include the key findings. During the usability of the model for specific chronic disease key finds can be placed in their relevant placeholders. Number of pathway stages to used depends on the nature and need for the disease.

To showcase an example of a care plan taking CAD into consideration a generalized scenario was created, highlighting some pain points and potential solutions defined in each stage of the care plan. We took a use case of middle-aged man, whose mother was a smoker, has an unhealthy diet and sedentary lifestyle (33, 34). A prehospital assessment revealed a high risk for heart disease. He experiences sudden chest pain and is admitted to the hospital, where he is diagnosed with myocardial infarction, along with a positive test for COVID 19 disease. This made it more complicated to understand the exact diagnosis or cause for his condition (35, 36). Hence, it became difficult

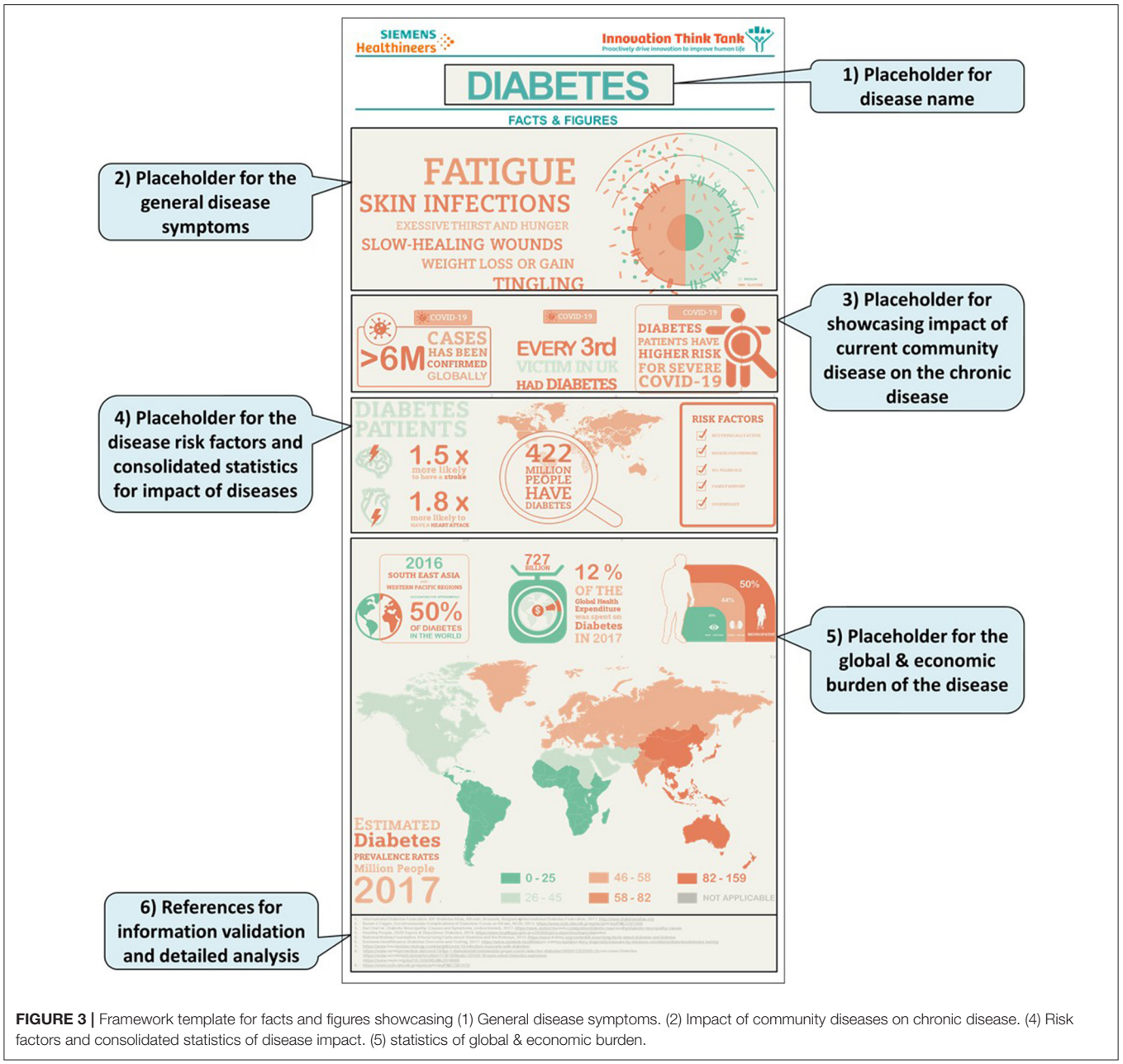


FIGURE 3 | Framework template for facts and figures showcasing (1) General disease symptoms. (2) Impact of community diseases on chronic disease. (4) Risk factors and consolidated statistics of disease impact. (5) statistics of global & economic burden.

to implement an appropriate treatment plan. Moreover, lack of rehabilitation exercises and shortage of medical staff due to pandemic, delayed his recovery. To avoid such pain points, technologies like artificial intelligence, machine learning, sensors and wearables, digital twin, 5G, telemedicine, virtual reality and robotics can be utilized to continuously monitor for early signs of warning, take preventive measures, aid in faster and accurate diagnosis, determine best course of treatment plan and provide robotic-assistance during rehabilitation and follow-up (37–43).

Based on the developed framework, we created disease pathways for 22 impacting diseases. The disease pathways were analyzed from the perspective of more than 20 stakeholders for the different stages of the care plan. As a result, a total of over 1,500 pain points were identified from multiple sources, including stakeholder interactions, clinical and disease workflow analyses, research, and requirements analyses of specific modalities. In addition, more than 1,900 ideas were proposed for the identified challenges. Some of these ideas are already being worked upon in ITT's research and development laboratories. The solutions were influenced by technological advances, business models, process improvements and clinical aspects. Thus, the technological solutions were distributed across three areas, namely digital technologies, which include the Internet of Medical Things (IoMT), the 5G mobile standard, artificial intelligence (AI) and blockchain; automated solutions such as robotics and sensors; and clinical innovations,

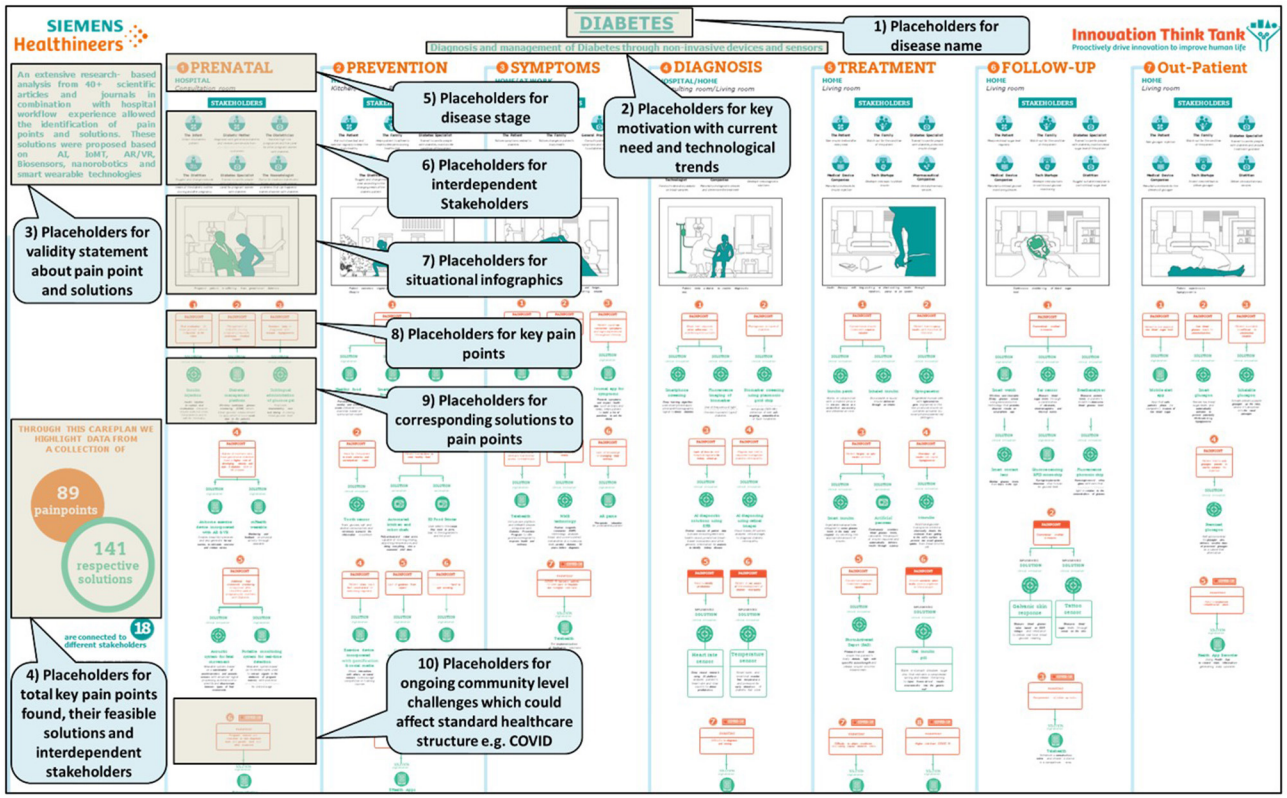


FIGURE 4 | Disease pathway framework in generalized format explaining the placement of framework elements.

which include new diagnostic methods, digital pathology, and minimally invasive procedures.

The pathways framework is a holistic approach, which institutions can use to collect their own pain points for their relevant stakeholders and come up with their customized solutions. We would also like to put a light on the ideal size for the framework templates is A3 (297 × 420 mm) or A2 (420 × 594 mm) for the best use and to visualize the consolidated view of a particular disease.

DISCUSSION

Based on the literature reviewed, it is evident that the global disease burden is rising and can prove to be catastrophic for the entire healthcare infrastructure. Our healthcare system is frail, and this has been proven multiple times, recently by the COVID-19 pandemic. We need a global multidisciplinary team comprising of clinical experts, medical technologists, policy makers, researchers, strategy and innovation experts, to identify the medical needs and develop innovative solutions that will deliver quality care to patients and improve outcomes, and this is what we have done in this study. Moreover, we focused on developing a common framework that can be applicable for all existing and new diseases as it provides a basic structure that can be easily used to curate disease pathways.

The disease pathway framework demonstrates the potential for incorporating some forward-thinking solutions to improve the patient experience. Predictive models can be used to identify individuals at high risk and take timely action (23). Chemoprophylaxis, vaccination, and other technological and clinical innovations may aid in disease prevention (26). Compiling information on existing diagnostic methods provides insight into the weaknesses of the current state of the art, based on which new solutions can be developed. It is important to invest in new tools and diagnostic technologies in addition to the usual strategies (44).

The disease pathway framework enables stakeholder mapping and provides important information about stakeholders' roles and influence on the different stages of the disease life cycle. For example, some of the stakeholders in the CAD care plan would be the patient, family, paramedics, nurse, cardiologist, and healthcare facility. These pathways also catalyze the identification of pain points and allow us to target the root cause efficiently. These pain points can be from the perspective of any stakeholder involved in the pathway. Understanding these challenges and stakeholder analysis helps identify areas for improvement related to clinical applications, products, processes, workflows, and patient-centered care. Mapping the portfolio in terms of disease pathways enables an organization to identify the white spots in the market. By identifying the pain points and white spots, considering the voices of key opinion leaders (KOLs)

and conducting hospital visits, information can be gathered about customers' needs and product requirements. Accordingly, decision suggestions can be made, and efficient solutions can be developed. The technological innovations can provide access to critical information for various stakeholders such as patients, physicians, hospital administrators, and government agencies. This can lead to improved patient experience and saving resources such as time and money. Thus, via the disease pathways, the framework can be used for:

1. Stakeholder Analysis
2. Pain point and root cause analysis
3. Portfolio Mapping and White spot analysis
4. Product requirement definition and Decision Proposition

The disease pathways created from this framework have been used in over 30 workshops, ITT certification programs (ITTCPs), and projects. The approach was applied to optimize use in 30 product and portfolio definition projects over 2 years at Siemens Healthineers and co-creation programs with universities and hospitals. The disease pathways helped identify the potential for improvement in various medical modalities such as CT, magnetic resonance imaging (MRI), molecular imaging (MI), X-ray equipment, surgical C-arms, angiography equipment, and laboratory diagnostics, to name a few. They also helped identify new potential disruptive areas related to technology and start-ups, opportunities to expand product portfolios, optimize clinical workflow, and enable patient-centered care. However, we also have few requirement-based limitations. If we take care of the following limitations, we can achieve best usability of the proposed framework. Disease pathways need to be adapted for different regions and locations. These pathways need to be updated regularly to reflect the latest trends and challenges. The pathways represent a very general set of best practices and pain points which need to be modified based on the healthcare systems in developed, developing, and underdeveloped countries.

Developing and implementing dedicated pathways requires a highly transdisciplinary approach with a global infrastructure consisting of trusted partners. This is often a challenge with traditional innovation approaches.

CONCLUSION

The disease pathway framework can be useful for healthcare providers, medical device manufacturers, start-ups, and other stakeholders to improve clinical workflows, enable patient-centered care, define product requirements, analyze gaps, and assess business impact. It provides a unique foundation for extensive collaboration among various stakeholders through information sharing and delivering high-quality solutions based on the identified problems and customer requirements.

The futuristic ideas presented here could be implemented in the hospital infrastructure in the future to solve some of the problems currently observed, such as social constraints during a pandemic, regular appointments with the appropriate experts, and improved quality of health care. A pathway for each disease can be created and extensive global clinical validation can be done after the Covid pandemic. A digital tool (web/mobile/tablet application) of the framework can be developed to overcome covid like situations.

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 in the article/supplementary material.

AUTHOR CONTRIBUTIONS

SH designed the disease pathway framework as the base for the study, conceived the original idea, and supervised and supported the project with respect to Siemens Healthineers. SH, AG, EW, SS, MM, SM, DH, and TP carried out the experiment. SH, AG, and MM wrote the manuscript with support from EW, SS, SM, DH, and TP. All authors contributed to the article and approved the submitted version.

FUNDING

This study received funding from Innovation Think Tank, Siemens Healthcare GmbH, Germany. The funder had the following involvement with the study: conceptualization, development, and manuscript writing.

ACKNOWLEDGMENTS

The author SH would like to thank the Innovation Think Tank teams who supported the project with their transdisciplinary expertise. SH would also like to thank Siemens Healthineers for the support.

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Conflict of Interest: SH, AG, EW, SS, MM, SM, DH, and TP were employed by Siemens Healthineers, Erlangen, Germany.

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CORRECTION
published: 29 June 2022
doi: 10.3389/fpubh.2022.931376

Corrigendum: A Disease Pathway Framework for Pain Point Identification and Elaboration of Product Requirements Across Patient Care Plan Using Innovation Think Tank Global Infrastructure

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Keywords: disease pathways, Innovation Think Tank, care plans, chronic disease management, disease statistics, healthcare system

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Edited and reviewed by:
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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *28 April 2022*
Accepted: *07 June 2022*
Published: *29 June 2022*

Citation:
Haider S, Goenka A, Mahmeen M, Sunny S, Phan T, Mehdi SA, Hassan DM and Weber E (2022) Corrigendum: A Disease Pathway Framework for Pain Point Identification and Elaboration of Product Requirements Across Patient Care Plan Using Innovation Think Tank Global Infrastructure. Front. Public Health 10:931376. doi: 10.3389/fpubh.2022.931376

A Corrigendum on

A Disease Pathway Framework for Pain Point Identification and Elaboration of Product Requirements Across Patient Care Plan Using Innovation Think Tank Global Infrastructure
by Haider, S., Goenka, A., Mahmeen, M., Sunny, S., Phan, T., Mehdi, S. A., Hassan, D. M., and Weber, E. (2022). Front. Public Health 10:862384. doi: 10.3389/fpubh.2022.862384

In the original article, there was an error. "We have provided all developed 22 impacting disease pathways in pdf format as the **Supplementary Files** because of the size constraints for the journal publication."

A correction has been made to **Results**, in the last paragraph:

"The pathways framework is a holistic approach, which institutions can use to collect their own pain points for their relevant stakeholders and come up with their customized solutions."

We received some important feedback regarding the **Supplementary Files** that they should be removed as precautionary measure for avoiding misunderstanding about the data presented, which need to be regularly updated. Therefore, for important reasons and on urgent basis, we request that the **Supplementary Files** should be removed. The removal of the **Supplementary Files** does not change the subject matter of the proposed framework.

The authors apologize for this error and state that this does not change the scientific conclusions of the article in any way. The original article has been updated.

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ORIGINAL RESEARCH
published: 28 April 2022
doi: 10.3389/fpubh.2022.865887

Global Trade Pattern of Traditional Chinese Medicines and China's Trade Position

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Edited by:
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Reviewed by:
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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *30 January 2022*
Accepted: *21 March 2022*
Published: *28 April 2022*

Citation:
Xiang L, Chen Z, Wei S and Zhou H (2022) Global Trade Pattern of Traditional Chinese Medicines and China's Trade Position. Front. Public Health 10:865887. doi: 10.3389/fpubh.2022.865887

To depict the evolution of the global trade of traditional Chinese medicine (TCM) products, this article analyzes the 2001–2020 trade data of TCM products in the World Bank and United Nations Commodity Trade Statistics Database to discern the spatial-temporal evolution characteristics of global and China's trade patterns of TCM products from 2001 to 2020 and thereby assess the changes in the global trade of TCM products and in the positions of various countries or regions in the global trade of TCM products. Research findings are as follows: First, on the whole, the total trade volume of TCM products and the number of participating economies and trade connections are on the rise. Second, in terms of topological structure, with higher network density and rising transmission efficiency, the global trade network of TCM products has typical small-world and scale-free network characteristics and has begun to be controlled by a few countries. Judging from the co-opetition between major trading countries, there are more diversified sources of imports for major trading countries, and there is competition between supplying countries. Third, For China, the trade volume of TCM products between China and various countries worldwide has grown rapidly and exhibits a trend of continuous increase followed by decline. China has established extensive trade partnerships and its position in the global trade network of TCM products has been continuously improved. China's participation has contributed to a closer connection among trading entities, but its network heterogeneity remains to be further improved. From the perspective of trade interdependence, the number of countries or regions maintaining high interdependence with China has been gradually increasing, and most of them are European and American countries, Japan, and Southeast Asian countries. The number of countries or regions maintaining low interdependence with China has gradually decreased, and countries or regions that are completely one-way dependent on China are nonexistent.

Keywords: trade of traditional Chinese medicine products, complex network, topological structure, spatial-temporal pattern, interdependence

INTRODUCTION

Traditional Chinese medicines (TCMs) are plants, animals, minerals, and their processed products used to prevent and treat human diseases based on the TCM theory. Conventional TCM products include TCM extracts, health foods, cosmetics, and daily necessities. In 2019, the total volume of TCM commodity imports and exports in China reached US$6.174 billion. Specifically, total exports were worth US$4.019 billion, up to 2.8% YoY; and total imports were worth US$2.155 billion, up to 15.9% YoY. With the deepening of China's opening up, the TCM industry has become a key driver of sustained development of China's health economy. Meanwhile, with dual attributes of science and technology and people's livelihood, the TCM industry is closely related to people's life safety and health and has gradually become a high technology industry that is being competitively developed across the world.

Due to the COVID-19 pandemic, the reconstruction of TCM industry chain has attracted unprecedented attention from the world. The main reason for such attention is the efficacy and economy of TCM products. During the combat against the COVID-19 virus, many TCM products were included in the sixth and seventh protocols for diagnosis and treatment released by China and showed satisfactory clinical effects. The mortality rate of the COVID-19 pandemic has been reduced effectively by the combination of traditional Chinese and western medicine.

According to the statistics from United Nations Commodity Trade Statistics Database, in terms of the total global trade volume of TCM products since 2009, the volatility rose and the average annual growth rate fell to 5.80%. The change in total trade volume is the combined outcome of changes in participating economies and trading volume and shows the increasing complexity of global TCM trade network. However, there are no studies directly discussing the current status of the global TCM trade network and its influencing factors. The following questions exist: Does the TCM trade network possess small-world and power-law characteristics? How will the complex game relations among countries or regions change amid the evolution of the global trade network dominated by major TCM trading countries? Is the relationship between supplying countries necessarily competitive? Ignoring these questions will hinder various countries' adjustment to their TCM industry development strategies and lower the industry's technical innovation efficiency and product quality. Therefore, this article analyzes the international trade network of TCM industry and its influencing factors in an attempt to answer the following questions: First, what changes have occurred to the international trade structure of TCM products? Second, what changes have occurred to the topological structure of the international TCM trade network? Does it have small-world and scale-free characteristics? What is the co-opetition between countries? What are the distribution and spatial patterns of trade groups like?

Considering the above questions, this article first sets up the global TCM trade network and analyzes the network's structural characteristics from the aspects of network connectivity and centrality. Then, with 2001 and 2020 selected as time nodes, the community network analysis method is adopted to look into the evolution characteristics of TCM trade groups and influencing factors of the formation of those groups. Finally, the co-opetition between major TCM trading countries is studied in terms of supply and demand to achieve a deeper understanding of the functionality and structure of the international TCM trade network and provide management implications for countries or regions in the TCM trade network.

Theoretical Basis

The international trade network is a complex economic system composed of interconnected economies and thus becomes a hot issue in the field of international trade. Based on the literature review, it is found that trade network has been studied from different disciplines and perspectives. In early research, the binary network was mainly adopted for the topology analysis of trade networks. Serrano and Boguna (1) built the trade network employing the complex network analysis method and identified the "small-world," "scale-free," and advanced network characteristics of the global trade network by building a trade network. Newman and Park (2) discovered the trade network's topological characteristics, such as betweenness and shortest path length. To gain a deeper insight into the evolution characteristic of the global trade network over time, Mahutga (3), Fagiolo et al. (4, 5), and Xi et al. (6) examined long-term evolution characteristics and arrived at the core-periphery structure, trade cluster, and other conclusions about economies in global trade. With the deepening of academic research, the study of trade networks was divided into the study of industries and the study of products, e.g., the trade of agricultural products and the energy industry (7–9). In addition, a number of scholars analyzed trade networks from regional perspectives, such as the Belt and Road region and Asia-Pacific Economic Region (10, 11).

Based on the review of literature, trade network has become the forefront of theoretical research of social network. Previous studies investigated the characteristics and patterns of trade networks by constructing a binary matrix or weighted directed network, which provides valuable insights for this article. However, the authors also find that further research is required in this field. First, there are few researchers looking into the pattern of TCM trade network from the perspective of whole network and research findings on changes in China's position are inadequate. Second, data mining work that can cover the entire time scale and evolution process of the global TCM trade network needs to be further expanded. The marginal contribution of this article is as follows: Based on the 2001–2020 global TCM trade data and with "TCM trade network" as the object of study, this article breaks the linear logic and considers both time and space dimensions. Through the construction of the 20-year evolution diagram of global TCM trade network, this article attempts to explore the evolution characteristics of the global TCM trade network and analyze the laws of change of China's position in TCM trade in an objective and comprehensive manner to provide a theoretical basis and decision-making support for China's efforts to cope with the changes in TCM trade pattern and build a TCM trade network system.

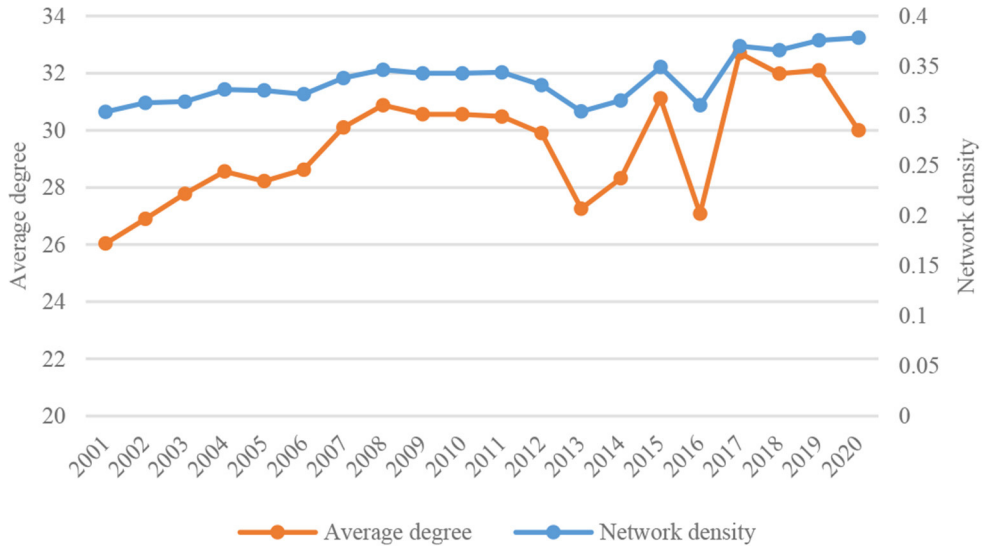


FIGURE 1 | Changes in average degree and density of global TCM trade network in 2001–2020.

RESEARCH METHODS AND RESULT ANALYSIS

Research Methods and Data

First of all, the trends of the trade of TCM products of China and the world are analyzed according to the changes in total trade volume. Second, the social network analysis approach is employed to look into the changes in the indicators of the global trade network of TCM products, including network density, average shortest path length, clustering coefficient, centrality, in-degree and out-degree, closeness centrality, betweenness centrality, and trade network group and thus reveal the evolution characteristics of the global trade network of TCM products.

Based on the existing research [e.g., 2, 9, 10] and for the sake of data integrity, this article analyzes the global trade of TCM products in detail through an empirical study of import and export data of TCM products defined under common Chinese Harmonized System (HS) codes 0507, 0510, 091020, 1211, 130190, 130211, 130219, 253090, and 3301. With countries or regions involved in the trade of TCM products abstracted as nodes, this article selects 100 countries or regions, including Mainland China and the United States, as the objects of the study. Given that the imports and exports of TCM products in these countries or regions in 2001–2020[1] account for 98.50% of the world's total, relevant data are highly representative. With a 100*100 matrix of trade network of TCM products built upon bilateral trade flows of the 100 countries or regions, Ucinet is used to analyze the characteristics of this network and Gephi is adopted for visualization of the trade network of TCM products.

[1]There are many missing values in the data before 2001. In order to ensure the integrity of the data, we selected the data after 2001 as the sample.

Evolution Characteristics of General Indicators of Global TCM Trade Network

On the whole, the density and transmission efficiency of the global TCM trade network have improved over time. In 2001–2020, the density of the global TCM trade network increased from 0.3042 to 0.3782 and the average degree increased from 26.04 to 30.00 and peaked at 32.70. A denser trade network means a closer relationship among member countries (**Figure 1**). The average clustering coefficient reflects the clustering degree among countries in the network. The larger the value, the higher the clustering, and vice versa. As shown in **Figure 2**, the average clustering coefficient of the global TCM trade network ranged between 0.446 and 0.495 and exhibited a general growth trend with fluctuations. A trend of increasing clustering is noticed within the network, especially since 2013. The average shortest path length represents the trade accessibility and network efficiency among member countries. The average path length of the global TCM trade network dropped from 1.491 to 1.403. This means higher connectivity of the network, reduced trade distance between any two economies, and generally improved network transmission efficiency.

The global TCM trade network has typical small-world and scale-free network characteristics. A network with a small average path length and a large clustering coefficient is deemed to have small-world network characteristics. As shown in **Figure 2**, the change trend of the average path length of the global TCM trade network is contrary to that of the average clustering coefficient. The minimum average shortest path length is 1.487, whereas the maximum clustering coefficient is 0.495. Since the former is about 3 times the latter, the global TCM trade network has typical small-world network characteristics.

Through the comparison among the node degree distribution curves of 2001, 2010, and 2020, the degree distribution curve of 2020 displays a typical long-tailed distribution (**Figure 3**). Power

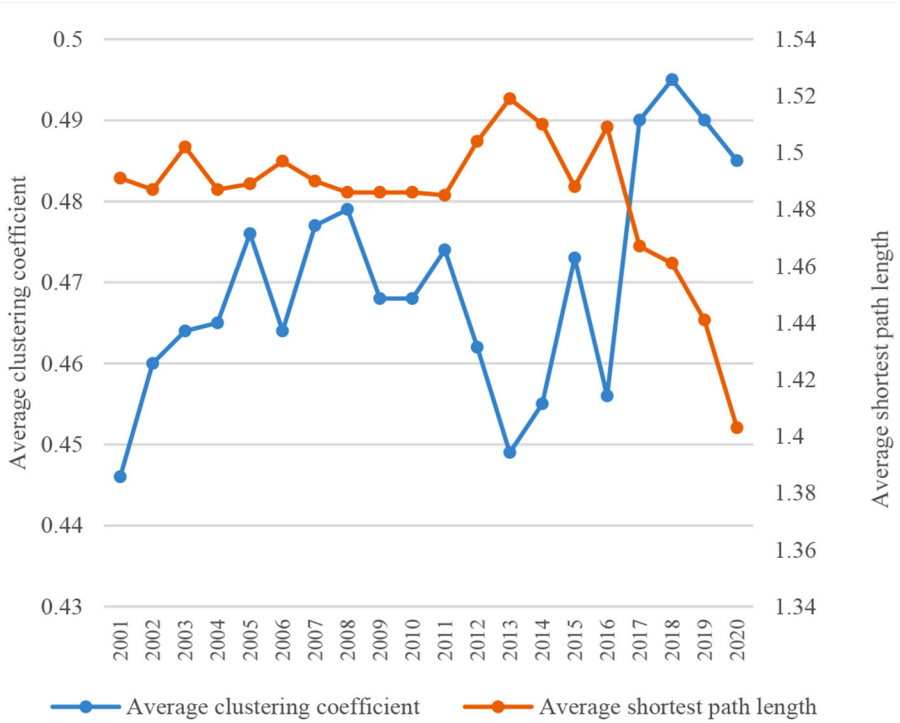


FIGURE 2 | Changes in average clustering coefficient and average shortest path length of global TCM trade network in 2001–2020.

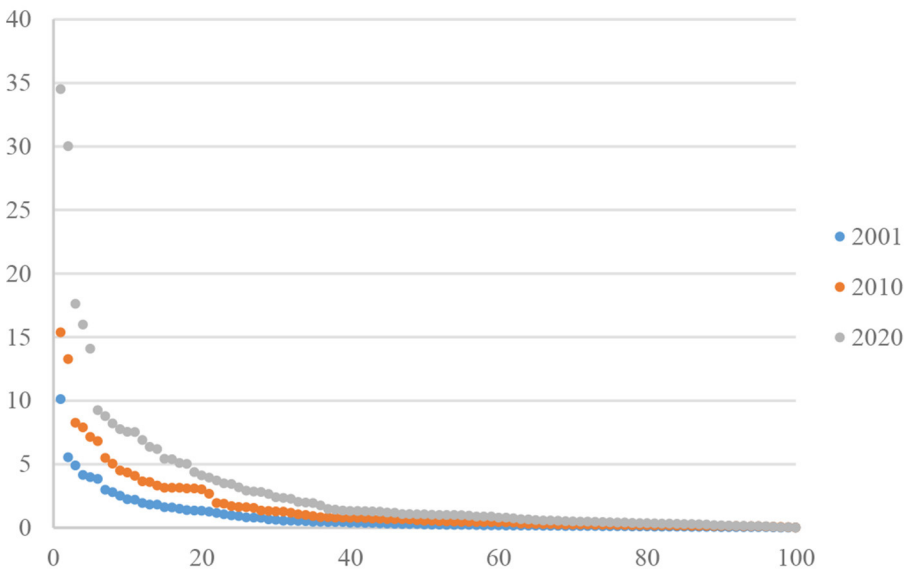


FIGURE 3 | Rank-node degree distribution of global TCM trade network.

function fitting is further done on the node degrees of the 3 years. The fitted equation for 2020 is: $y = 220.19x^{-1.467}$, $R^2 = 0.8{,}051$, $p = 0.001$, passing the significance test. This means that the degree follows a power-law distribution. In other words, there were few nodes with high weighted degree and most nodes had low weighted degree in 2020. This follows the scale-free law and indicates that the global TCM trade network began to be controlled by only a few countries.

TABLE 1 | Top 10 countries by weighted degree, weighted in-degree, and weighted out-degree in 2001 and 2020.

2001						2020					
Country/region	**C**	**Country/region**	**OD**	**Country/region**	**ID**	**Country/region**	**C**	**Country/region**	**OD**	**Country/region**	**ID**
US	101,026	France	83	France	78	US	345,061	Germany	82	Germany	71
China	55,342	America	77	Germany	74	China	300,060	China	81	China	68
France	48,939	Germany	75	America	68	India	176,016	America	80	US	68
Japan	41,428	UK	75	UK	67	Germany	159,717	India	78	France	66
Hong Kong, China	39,605	India	67	Spain	67	France	140,686	Spain	75	India	65
Germany	38,246	Spain	67	India	61	Spain	92,388	France	73	Spain	64
UK	29,737	Italy	63	Switzerland	60	Japan	87,643	UK	70	UK	61
India	27,864	Japan	59	Italy	56	Republic of Korea	81,881	The Netherlands	64	Italy	59
Spain	25,081	Switzerland	58	The Netherlands	55	The Netherlands	77,393	Egypt	63	The Netherlands	55
South Korea	22,184	The Netherlands	52	China	52	Hong Kong, China	75,370	Switzerland	58	Switzerland	51

TABLE 2 | Top 10 countries by closeness centrality and betweenness centrality in 2001 and 2020.

2001				2020			
Country/region	**Closeness centrality**	**Country/region**	**Betweenness centrality**	**Country/region**	**Closeness centrality**	**Country/region**	**Betweenness centrality**
France	88.889	France	11.565	US	46.919	US	8.091
Germany	83.838	Germany	8.222	China	46.698	China	7.558
UK	79.798	US	6.511	Germany	46.479	France	5.986
US	79.798	UK	5.285	France	45.833	Germany	5.403
Spain	74.747	India	4.819	India	45.833	India	4.993
India	72.727	Spain	4.357	Spain	45.205	Spain	4.722
Switzerland	68.687	Italy	3.13	UK	44.395	UK	2.948
Italy	67.677	China	3.074	The Netherlands	43.805	Egypt	2.753
China	64.646	Switzerland	2.713	Italy	43.231	The Netherlands	2.41
The Netherlands	63.636	Japan	2.297	Egypt	42.857	Italy	1.964

Analysis of Core Countries in the Global TCM Trade Network

The weighted degree reflects the position of economies in the global TCM trade market to some extent. All the top 10 countries, except the UK, by weighted degree in 2001 remained in the top 10 in 2020. Specifically, the US ranked first with a weighted degree of 345,061 and China ranked second with 300,060 in 2020. Outdistancing other countries, both the US and China are undisputedly the largest TCM trading countries in the world. However, the global TCM trade pattern changed in 2020. Japan and Hong Kong of China exited from the list of top 5 by weighted degree and the trading position of East Asia generally declined. Meanwhile, India's position rose in the global TCM trade (**Table 1**).

Weighted in-degree and weighted out-degree reflect the import and export position of economies in global TCM trade. The list of top 10 countries by weighed out-degree remained relatively stable. France, the US, Germany, the UK, Japan, Switzerland, and The Netherlands stayed in the top 10 for a long time and have long dominated the global TCM export market. In addition, China and Egypt rose quickly into the top 10 rankings by weighted out-degree in 2020. In particular, China ranked only second to the US by weighted out-degree and has become an important node in the global TCM export market. In terms of weighted in-degree, the list of the top 10 countries remained relatively stable. Germany ranked first and China moved to second place in 2020 (**Table 1**).

Closeness centrality represents the sum of trade connection distances between economies. The higher this value is, the closer a particular economy is to other economies in the trade network. Closeness centrality also indicates the independence and ability to get out of control for a particular node. In terms of closeness centrality (**Table 2**), the top 10 list in 2001 was dominated by developed European and American countries, including France, Germany, the UK, the US, Spain, Switzerland, Italy, and The Netherlands. The top 10 list in 2020 was the same as that in 2001, except that Switzerland was replaced by Egypt. Moreover, 2/3 of the top 10 countries by closeness centrality were also top 10 countries by in-degree or out-degree. This shows that the global TCM trade network basically follows a peer-to-peer architecture.

Betweenness centrality is the fraction of international shortest trade connection paths going through a particular economy in the global TCM trade network and reflects the node's control over resources flow. The larger the value, the greater the control. In

TABLE 3 | Co-opetition between major importers of TCM products in 2020[a].

Rank	Exporter	Group	Importer	Group	Concentration	Rank	Exporter	Group	Importer	Group	Concentration
1	The Netherlands	P1	US	P4	30.95%	29	Germany	P1	Spain	P1	8.18%
2	India	P4	China	P3	27.13%	30	UK	P1	Germany	P1	8.07%
3	US	P4	India	P4	25.25%	31	France	P1	Italy	P1	8.00%
4	Egypt	P4	India	P4	22.52%	32	France	P1	China	P3	7.87%
5	China	P3	US	P4	22.04%	33	France	P1	US	P4	7.75%
6	Egypt	P4	China	P3	21.00%	34	France	P1	Spain	P1	7.62%
7	China	P3	India	P4	19.60%	35	India	P4	US	P4	7.24%
8	Switzerland	P1	US	P4	17.32%	36	Spain	P1	US	P4	7.21%
9	US	P4	China	P3	16.30%	37	Germany	P1	France	P1	7.11%
10	Spain	P1	China	P3	14.92%	38	Switzerland	P1	Italy	P1	7.07%
11	Switzerland	P1	Germany	P1	14.62%	39	Spain	P1	Iran, Islamic Republic of	P3	7.02%
12	Switzerland	P1	France	P1	14.59%	40	India	P4	Vietnam	P3	6.71%
13	UK	P1	US	P4	13.85%	41	The Netherlands	P1	China	P3	6.41%
14	UK	P1	France	P1	13.66%	42	France	P1	Germany	P1	6.35%
15	UK	P1	China	P3	12.23%	43	China	P3	Korea, Republic of	P3	6.35%
16	The Netherlands	P1	Germany	P1	11.81%	44	France	P1	Morocco	P1	6.25%
17	Spain	P1	France	P1	11.71%	45	Spain	P1	Germany	P1	6.09%
18	India	P4	Indonesia	P2	10.98%	46	Egypt	P4	US	P4	6.06%
19	UK	P1	India	P4	9.99%	47	Egypt	P4	Germany	P1	6.04%
20	Germany	P1	India	P4	9.54%	48	Spain	P1	Italy	P1	6.03%
21	France	P1	India	P4	9.40%	49	UK	P1	Spain	P1	6.03%
22	Germany	P1	US	P4	9.39%	50	US	P4	Mexico	P4	5.91%
23	India	P4	Afghanistan	P2	9.27%	51	The Netherlands	P1	Belgium	P1	5.73%
24	Germany	P1	Brazil	P3	8.58%	52	Switzerland	P1	Indonesia	P2	5.50%
25	The Netherlands	P1	France	P1	8.50%	53	The Netherlands	P1	UK	P1	5.21%
26	US	P4	France	P1	8.46%	54	Spain	P1	India	P4	5.03%
27	Egypt	P4	Tunisia	P1	8.36%	55	France	P1	Belgium	P1	5.00%
28	Germany	P1	China	P3	8.36%						

[a] *In 2020, global trade groups of TCM products include: P1 group composed of 14 economies including France, Italy, and Poland, etc.; P2 group composed of 13 economies including United Arab Emirates and Singapore, etc.; P3 group composed of 23 economies including China, Japan, and South Korea, etc.; P4 group composed of 21 economies including the US, Australia, and Canada, etc.*

terms of betweenness centrality (**Table 2**), France, Germany, the US, the UK, India, Spain, Italy, and China stayed in the top 10 list from 2001 through 2020. Those countries played a vital role and were the major players in the global TCM trade network. Switzerland and Japan declined in their rankings by betweenness centrality, whereas Egypt and The Netherlands rose quickly into the top 10 list. A comparison of the top 10 lists by betweenness centrality, out-degree, and in-degree reveals high similarity, with 8 countries appearing in all the three lists. This shows that the control in TCM trading relationships is directly reflected in the dependence and vulnerability between TCM trading countries.

Co-opetition Between Major Trading Countries in Global Trade of TCM Products

Higher Diversification of Import Sources for Major Trading Countries From the Cooperation Perspective

Trade partners of the top 10 economies in 2020 by weighted in-degree with an import concentration above 5% are selected to build a partial trade network for analysis (**Table 3**). From the demand-side perspective, major importers of TCM products in 2020 included Germany, China, the US, France, India, Spain, Italy, The Netherlands, and Switzerland.

Within P1, Switzerland's imports from Germany, France, and Italy represent 14.62, 14.59, and 7.07% of its total import of TCM products, respectively. UK's imports from France, Germany, and Spain represent 13.66, 8.07, and 6.03% of its total, respectively. The Netherlands' imports from Germany, France, Belgium, and the UK represent 11.81, 8.50, 5.73, and 5.21% of its total, respectively, and Spain's imports from France, Germany, and Italy represent 11.71, 6.09, and 6.03% of its total, respectively. France's imports from Italy, Spain, Germany, Morocco, and Belgium represent 8.00, 7.62, 6.35, 6.25, and 5.00% of its total, respectively. It is thus clear that Spain and France are important trade partners for each other. By comparison, France had more sources of imports and a low market concentration, whereas Spain had fewer sources of imports and a high market concentration. Within P4, the US and India are important trade partners for each other, and the US, India, and Egypt all have low import concentrations. Outside the groups, P1 and P4 are mainly connected by The Netherlands–US connection. The Netherlands is the largest importer of TCM products from the US, accounting for 30.95% of its total. P3 and P4 are mainly connected by the China–US and China–India connections. P2 and P4 are mainly connected by the India–Indonesia and India–Afghanistan connections. These countries are hubs for the trade of TCM products within and outside the groups.

Among the major purchasing countries or regions of TCM products, China and US had the smallest number of import sources, which were 3 and 4, respectively. India, Egypt, and Switzerland each had 5 sources of imports. Germany and UK each had 6 sources of imports. Spain and France had the largest number of import sources, which were 7 and 8, respectively. In terms of import and export concentration of TCM products, among the top 10 supplying countries, there were 2 countries with an export concentration of >20–30% for their major export partners and 8 countries with 10–20%. By comparison, among the major TCM purchasing countries, there were 3 countries with an import concentration below 10% and 7 countries with 10–20%. In addition, the average number of export partners for TCM supplying countries was 5.3, whereas the 10 major importing countries each had 5.5 sources of imports on average. It is thus evident that the diversification of import sources for major TCM purchasing countries is slightly higher than that of exporters and their import concentration is also slightly lower than the export concentration of major TCM supplying countries. This means importing countries pay more attention to the diversified TCM development strategy.

Competition Among All Supplying Countries From the Competition Perspective

The macroscopic expression of co-opetition in the trade of TCM products is the co-opetition between trade groups dominated by major countries. The mesoscopic expression is the trade between countries or regions and the derived co-opetition. Trade partners of the top 10 economies by weighted out-degree in 2020 with an export concentration above 5% are selected to form a partial trade network for analysis (**Table 4**). From the supply perspective, major exporters of TCM products in 2020 included Germany, China, the US, India, Spain, France, the UK, The Netherlands, Egypt, and Switzerland. Among others, India exported 39.64% of its TCM products to the US, which was its only major export partner. India and China had 3 and 4 major export partners, respectively, to which they exported 18.19 and 13.79% of their total, respectively. The Netherlands, the US, Spain, and the UK each had 5 major export partners, with an export concentration of 11.03, 9.05, 11.81, and 9.74%, respectively. Italy had 6 export partners with an export concentration of 9.84%. As the countries with the highest export diversification, Germany and France each had 7 major export partners, with an export concentration of 7.50 and 9.50%, respectively.

For TCM supplying countries, the export targets of major supplying countries are the basis of their competitive relationship. Generally speaking, there is competition between supplying countries with the same export direction. Since the foregoing major TCM exporters have the demand to export their TCM products to global markets, there is potential competition among them. Judging from their major export partners, there is competition among all major exporting countries. Both The Netherlands and Switzerland had a large TCM trade with Germany and the US, so there is competition between them. Spain and Italy also had intensive TCM trade relations with those European and American countries. Therefore, there is competition among The Netherlands, Switzerland, Spain, and Italy. Hence, it cannot be generalized whether there is competition between the TCM supplying countries. All in all, there is a competition for European and American markets among The Netherlands, Switzerland, Spain, and Italy.

TABLE 4 | Co-opetition among major exporters of TCM products in 2020.

Rank	Exporter	Group	Importer	Group	Concentration (%)	Rank	Exporter	Group	Importer	Group	Concentration (%)
1	India	P4	US	P4	39.64	28	Switzerland	P1	Luxembourg	P1	7.52
2	France	P1	US	P4	22.56	29	Germany	P1	Austria	P1	7.23
3	China	P3	US	P4	18.78	30	UK	P1	The Netherlands	P1	7.21
4	Switzerland	P1	US	P4	18.69	31	France	P1	UK	P1	7.08
5	Spain	P1	US	P4	17.66	32	France	P1	Switzerland	P1	7.02
6	Italy	P1	France	P1	17.47	33	Spain	P1	UK	P1	6.99
7	The Netherlands	P1	Germany	P1	17.37	34	Germany	P1	Switzerland	P1	6.90
8	Spain	P1	Germany	P1	16.93	35	UK	P1	France	P1	6.76
9	Italy	P1	US	P4	16.80	36	India	P4	Germany	P1	6.71
10	China	P3	Japan	P3	16.71	37	Germany	P1	The Netherlands	P1	6.63
11	Switzerland	P1	Germany	P1	16.55	38	Germany	P1	France	P1	6.62
12	Germany	P1	US	P4	13.47	39	Switzerland	P1	UK	P1	6.47
13	France	P1	Germany	P1	13.44	40	The Netherlands	P1	US	P4	6.16
14	The Netherlands	P1	Poland	P1	13.43	41	US	P4	Germany	P1	6.13
15	UK	P1	Ireland	P5	12.83	42	Germany	P1	UK	P1	5.92
16	US	P4	Canada	P4	12.82	43	US	P4	Japan	P3	5.79
17	US	P4	China	P3	12.12	44	Germany	P1	Poland	P1	5.71
18	Spain	P1	France	P1	12.05	45	France	P1	The Netherlands	P1	5.62
19	China	P3	Hong Kong, China	P3	11.73	46	Switzerland	P1	Italy	P1	5.56
20	UK	P1	US	P4	11.61	47	Switzerland	P1	France	P1	5.54
21	UK	P1	Germany	P1	10.30	48	France	P1	Italy	P1	5.43
22	The Netherlands	P1	UK	P1	10.19	49	Spain	P1	Italy	P1	5.41
23	Italy	P1	Germany	P1	9.29	50	France	P1	Belgium	P1	5.33
24	US	P4	The Netherlands	P1	8.36	51	Italy	P1	Spain	P1	5.27
25	India	P4	China	P3	8.22	52	Italy	P1	Japan	P3	5.13
26	The Netherlands	P1	Croatia	P1	7.99	53	Italy	P1	UK	P1	5.06
27	China	P3	Korea, Republic of	P3	7.92%						

EVOLUTION OF CHINA'S TRADE OF TCM PRODUCTS

Evolution of Overall Trade Structure Over Time

The total trade volume of TCM products between China and other countries grew quickly and exhibited a trend of continuous increase followed by decline (**Figure 4**). The total volume of imports and exports, total exports, and total imports of China with other countries all exhibited a rising trend since China's accession to WTO in 2001, followed by a decline after 2014. The period from 2001 to 2014 was a "golden period" for China's trade of TCM products. The trade volume rose steadily from US$394 million in 2001 to US$3.107 billion in 2014, with an average annual growth rate of 17.89%. After 2014, China's trade volume of TCM products dropped significantly and stood at US$2.557 billion in 2017. Since then, the figure has begun to grow slowly.

Evolution in Terms of Importers and Exporters

In terms of imports from major TCM trading countries from 2001 to 2020 (**Figure 5**), China's imports from Canada have been declining, while thosefrom the US and India have been gradually increasing. Due to China's huge import demand for TCM products from the US and India, they have become China's biggest suppliers of TCM products. For China, other major suppliers of TCM products include South Korea, France, and Canada. In terms of exports to major TCM trading countries in 2001–2020 (**Figure 5**), the US overtook Japan as China's largest export destination, followed by Japan. Major export destinations of China were mostly East and Southeast Asian countries and developed countries in Europe and America.

China's Position in Global Trade Network of TCM Products

Extensive Trade Partnerships Established by China

The centrality of global trade network of TCM products for China peaked in 2015 when it established trade relations with 99 countries or regions (**Figure 6**). This means that on the one hand, China has maintained trade relationships with more economies. Its trade partners are more widely distributed in the world and other economies have higher trade dependence on China. On the other hand, China will have larger and more diversified markets and smaller trade risks, suggesting a better position to select its trade partners and optimize its trade structure. It indicates that China occupies a pivotal position in the global trade of

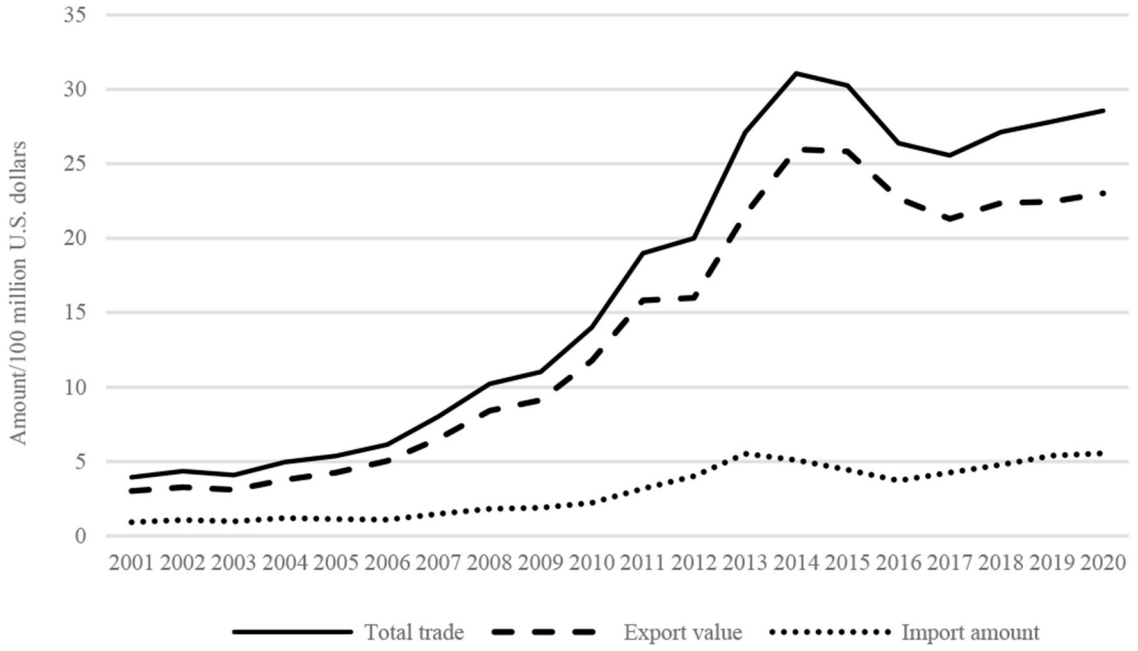


FIGURE 4 | Evolution of China's imports and exports of TCM products in 2001–2020.

TCM products and enjoys a stronger control ability and a higher comparative advantage. China has maintained a core position in the global trade network of TCM products for the past 20 years.

China's Trade Network Heterogeneity Needs to Be Improved

Figure 7 shows the changes in the ranking of China by structural hole index from 2001 to 2020. In 2001, China ranked 90th with a limitation of 0.073. Afterward, its ranking gradually increased with the declining limitation. In 2007, China rose to 95th with the limitation of 0.058. It ranked 100th in both 2015 and 2016 and ranked 97th in 2020. Obviously, with the declining limitation, China has a stronger ability to occupy structural holes, and its position in the trade network of TCM products has also been continuously improved. Judging from the structural hole index, although China's trade network heterogeneity has improved, it still lags behind other countries. China's trade partnerships are relatively concentrated, thus posing certain trade risks, and its trade network heterogeneity remains to be boosted. China needs to reduce its dependence on existing trade partners by optimizing its geographical and product structures of TCM trade.

China's Rising Position in Global Trade Network

Multidimensional scaling (MDS) is a multivariate statistical analysis approach that reflects the correlation between objects in the form of spatial distribution. An MDS map presents an approximate image that visually reflects the interrelations between some high-dimensional sample points in a lower-dimensional space, thus providing information on the relative position of each network node in the trade network and the intimacy of interrelation. The central point of an MDS map represents the central position of the network. The closer a node is to the central point, the closer it is to the center of the network, and the higher its relative position in the network. As shown in **Figure 8**, Mainland China gradually moved from a semi-periphery position to a central position. Compared with 2001, Mainland China was the closest to the coordinate center in 2020. This indicates that Mainland China plays a vital role in the global trade network of TCM products, which is consistent with the above conclusions obtained with the degree centrality and structural hole index. It can also be found in **Figure 8** that China, Japan, South Korea, and the US have remained at the central position of the network for the past 20 years, signifying their high positions in the network.

China's Significant Impact on Node Connection in Trade Network

As shown in **Table 5**, the density of the global trade network of TCM products rose gradually from 2001 to 2020. In 2020, the network density was 1.24 times that in 2001, indicating an increasingly close global trade network of TCM products. Since 2015, China's inclusion in the global trade network of TCM products has improved the network density to different degrees. It indicates that the participation of China has contributed to a closer connection among trading entities.

Interdependence of China in the Trade of TCM Products

Based on the foregoing analysis and **Figure 5**, China's import and export market is similar to that of the world. In terms of trade volume, China's trade of TCM products is highly concentrated.



FIGURE 5 | China's imports and exports in 2001, 2010, and 2020.

The sum of the import and export volume between China and its top 20 trading partners accounted for more than 85% of its total in 2001, 2010, and 2020, respectively. In terms of spatial distribution, China's import market has been further concentrated in East and Southeast Asian countries, and its export market has begun to be concentrated in European and American countries.

To better portray the interdependence between China and its trading partners in the trade of TCM products, and considering high concentration of China's trade volume of TCM products, this study adopts the independence index model to calculate China's interdependence index with its major trading partners of TCM products in 2001, 2010, and 2020, respectively (**Table 6**). In terms of the trade of TCM products, the interdependence

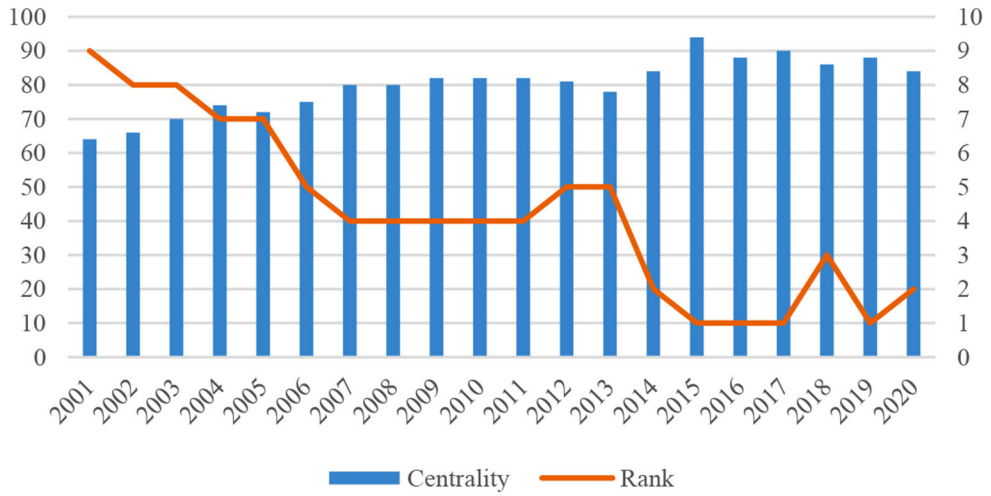


FIGURE 6 | China's network centrality and rank from 2001 to 2020.

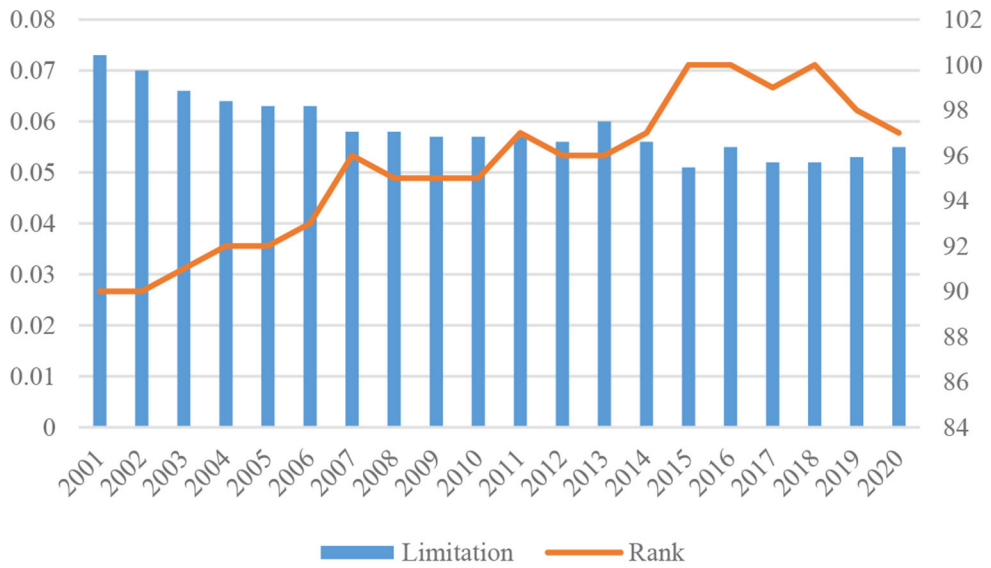


FIGURE 7 | China's structural hole index and rank in 2001–2020.

between China and developed countries or regions, like Canada, Italy, and France, has generally increased, while that with the US and Singapore has decreased significantly. Furthermore, for most European countries or regions with high interdependence with China, China's exports to them were lower than their exports to China, which indicates that China is more dependent on those countries or regions. Meanwhile, China's exports to countries or regions with low interdependence have gradually increased and were much higher than their exports to China, resulting in low interdependence but high one-way dependence.

According to the ranking of China's major trading partners by the interdependence index (**Table 7**), the number of countries or regions that maintain high interdependence with China on the trade of TCM products has gradually increased and they are mostly European and American countries, Japan, and Southeast Asian countries. The number of countries or regions that maintain low interdependence with China has gradually decreased, and the countries or regions that are completely one-way dependent on China are nonexistent.

On the whole, China has established extensive interdependent relations and almost no one-way dependent relations. Among its major trading partners of TCM products, the interdependence of China with European and American countries, Japan, and Southeast Asian countries has generally deepened.

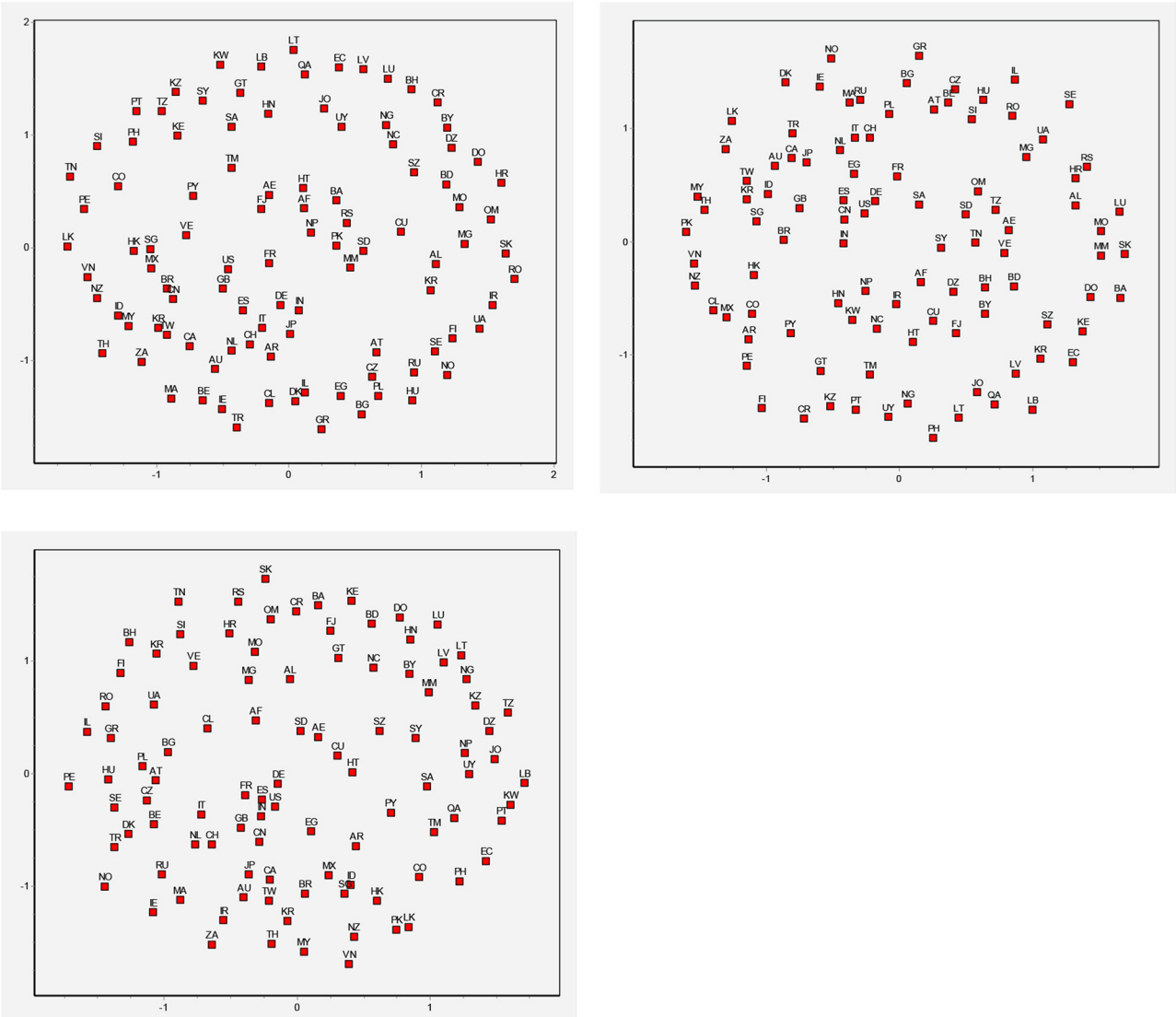


FIGURE 8 | MDS analysis for China in 2001, 2010, and 2020. Afghanistan, AF; Albania, AL; Algeria, DZ; Argentina, AR; Australia, AU; Austria, AT; Bangladesh, BH; Belarus, BD; Belgium, BY; Bosnia and Herzegovina, BE; Brazil, BA; Bulgaria, BR; Chile, BG; Columbia, CA; Costa Rica, CL; Croatia, CN; Cuba, CO; Czech Republic, CR; Denmark, HR; Dominican Republic, CU; Ecuador, CZ; Egypt, DK; Fiji, DO; Finland, EC; France, EG; Germany, SZ; Greece, FJ; Guatemala, FI; Haiti, FR; Honduras, DE; Hungary, GR; India, GT; Indonesia, HT; Ireland, HN; Israel, HK; Italy, HU; Kazakhstan, IN; Kenya, ID; Latvia, IR; Lithuania, IE; Luxemburg, IL; Madagascar, IT; Mexico, JP; Morocco, JO; Nepal, KZ; Netherlands, KE; New Caledonia, KR; Nigeria, KR; Norway, KW; Pakistan, LV; Paraguay, LB; Peru, LT; Philippines, LU; Poland, MO; Portugal, MG; Romania, MY; Russian Federation, MX; Slovakia, MA; Slovenia, MM; North Africa, NP; Spain, NL; Sri Lanka, NC; Sweden, NZ; Switzerland, NG; United Republic of Tanzania, NO; Tunisia, OM; Turkey, PK; Ukraine, PY; United Kingdom, PE; United States of America, PH; Uruguay, PL; Bolivarian Republic of Venezuela, PT; Bahrain, QA; Canada, RO; China, RU; Eswatini, SA; Hong Kong, China, RS; Islamic Republic of Iran, SG; Japan, SK; Jordan, SI; North Korea, ZA; South Korea, ES; Kuwait, LK; Lebanon, SD; Macau, China, SE; Malaysia, CH; Burma, SY; New Zealand, TW; Oman, TZ; Qatar, TH; Saudi Arabia, TN; Serbia, TR; Singapore, TM; Sudan, UA; Syrian Arab Republic, AE; Chinese Taipei, GB; Thailand, US; Turkmenistan (The Mirror), UY; United Arab Emirates, VE; Viet Nam, VN.

TABLE 5 | China's impact on trade network in 2001–2018.

Year	2001	2005	2010	2015	2020
Density of TCM product trade network	0.3042	0.3256	0.3427	0.3490	0.3782
Density of TCM product trade network without inclusion of China	0.3107	0.3355	0.3476	0.3552	0.3651

TABLE 6 | Interdependence between China and its top 20 trading partners in 2001, 2010, and 2020.

Rank	2001		2010		2020	
	Country/region	$DrGL_{i,j}$	Country/region	$DrGL_{i,j}$	Country/region	$DrGL_{i,j}$
1	Japan	0.08	Japan	0.07	US	0.43
2	US	0.73	Hong Kong, China	0.01	Japan	0.04
3	Hong Kong, China	0.04	US	0.73	Hong Kong, China	0.01
4	South Korea	0.03	South Korea	0.14	Republic of Korea	0.31
5	Canada	0.12	Vietnam	0.04	India	0.51
6	Chinese Taipei	0.29	India	0.78	Chinese Taipei	0.05
7	Singapore	0.84	Chinese Taipei	0.15	Mexico	0.07
8	UK	0.16	Spain	0.05	Germany	0.23
9	France	0.55	Singapore	0.22	Malaysia	0.00
10	Germany	0.32	Germany	0.19	Indonesia	0.51
11	India	0.47	Mexico	0.01	Vietnam	0.34
12	Spain	0.36	France	0.39	Spain	0.10
13	Indonesia	0.47	Indonesia	0.6	France	0.75
14	Vietnam	0.36	UK	0.5	Canada	0.86
15	The Netherlands	0.24	The Netherlands	0.65	Australia	0.48
16	Italy	0.11	Malaysia	0.01	Thailand	0.36
17	Malaysia	0.09	Australia	0.56	UK	0.36
18	United Arab Emirates	0	Thailand	0.66	Singapore	0.07
19	Australia	0.19	Italy	0.43	New Zealand	0.59
20	Brazil	0.68	Argentina	0.13	Italy	0.76

TABLE 7 | Ranking of China's top 20 trading partners in trade of TCM products by interdependence in 2001, 2010, and 2020.

Interdependence	2001	2010	2020
High	Singapore, US, Brazil, France	India, US, Thailand, The Netherlands, Indonesia, Australia, UK	Canada, Italy, France, New Zealand, India, Indonesia
Medium	India, Indonesia, Spain, Vietnam, Germany, Chinese Taipei, The Netherlands	Italy, France, Singapore	Australia, US, Thailand, UK, Vietnam, South Korea, Germany
Low	Australia, the UK, Canada, Italy, Malaysia, Japan, Hong Kong (China), South Korea, United Arab Emirates	Germany, Chinese Taipei, South Korea, Argentina, Japan, Spain, Vietnam, Mexico, Malaysia, Hong Kong (China)	Spain, Mexico, Singapore, Chinese Taipei, Japan, Hong Kong (China), Malaysia

CONCLUSION AND DISCUSSION

Conclusion

To depict the evolution of the global trade of TCM products, this article analyzes the 2001–2020 trade data of TCM products in the World Bank and United Nations Commodity Trade Statistics Database to discern the spatial-temporal evolution characteristics of global and China's trade patterns of TCM products from 2001 to 2020 and thereby assess the changes in global and China's trade of TCM products and in China's position in the global trade of TCM products. The major findings of this study are as follows.

First, the total trade volume of TCM products is generally on the rise. The changes in total trade volume are the combined outcome of changes in participating economies and trade volumes. The development trends of the number of participating economies and trade connections generally correspond to the total trade volume. With increasing interactions and interdependence, TCM trade connections between countries or regions have strengthened.

Second, in terms of topological structure, with higher density and rising transmission efficiency, the global trade network of TCM products has typical small-world and scale-free network characteristics and has begun to be controlled by a few countries. Based on the analysis of core countries, China and the US are undisputedly the largest TCM traders in the world. The global trade network of TCM products basically follows a peer-to-peer architecture. The control in TCM trade is directly reflected in the dependence and vulnerability between TCM trading countries. Judging from co-opetition between major trading countries, there are more diversified import sources for major trading countries, and there is competition between supplying countries.

Third, for China, the trade volume of TCM products between China and various countries worldwide has grown rapidly and exhibits a trend of continuous increase followed by decline. In terms of imports from major trading countries, China's imports from Canada have been declining, while those from the US and India have been gradually increasing. In terms of exports, the major export destinations of China were mostly

East and Southeast Asian countries and developed countries in Europe and America. China has established extensive trade partnerships and its position in the global trade network of TCM products has been continuously improved. China's participation has contributed to a closer connection among trading entities, but its network heterogeneity remains to be further improved.

From the perspective of trade interdependence, the number of countries or regions maintaining high interdependence with China has been gradually increasing, and most of them are European and American countries, Japan, and Southeast Asian countries. The number of countries or regions maintaining low interdependence with China has been gradually decreasing, and countries or regions that are completely one-way dependent on China are nonexistent.

Theoretical Contributions

The global economic situation is currently complicated, and reverse globalization and new trade protectionism are on the rise. The trade of TCM products is also affected. An in-depth analysis of the global TCM trade network is of positive significance to the development of global TCM trade and the quality improvement of China's TCM import and export trade.

In terms of theoretical foundation and hypothesis, previous studies on TCM trade focused more on technology transfer (12), potential estimation (13, 14), and influencing factors (15, 16). Unlike previous studies, this article adopts a multi-year scale approach to discuss the overall structural evolution of global TCM trade from a more macroscopic perspective. Similar to the findings by Hinsley et al. (17) and Cheung et al. (18), this article proceeds from the perspective of complex network and draws conclusions, including scale-free characteristics and shift of focus of import and export in the global trade of TCM products, asserting the existence of dependence and competition among countries or regions. Unlike previous studies, the results of this study show that the global TCM trade network is a typical small-world network that is closely connected and continuously expanding. Major export destinations of China were mostly East and Southeast Asian countries and developed countries in Europe and America. Moreover, this network follows a peer-to-peer architecture. The control in TCM trade relationship is directly reflected in dependence and vulnerability between TCM trading countries.

This article reveals the evolution characteristics of spatial-temporal pattern of global trade of TCM products and explains the changes in the trade network from various perspectives. The conclusions are believed to assist in China's adjustment of its TCM products import and export policies and help China make breakthroughs in the development of emerging markets. This research is also a meaningful exploration for China's communication and cooperation with other countries on TCM products. This research also fills a gap in previous studies by delving into spatial-temporal evolution of TCM trade and for the first time discusses the trade groups, spatial pattern, and evolution of import and export structure of TCM products. This study is a significant contribution from both theoretical and practical perspectives.

On the whole, this article has two new elements compared with existing research findings: First, it provides a new perspective on the TCM trade. Most existing studies look into the current status and trade potential of the TCM trade industry (12, 15), and there are few studies focusing on the spatial-temporal evolution of import and export trade of TCM products, which actually has an important influence on imports and exports of the TCM products industry. Second, this study applies an existing methodology in a new context. This article adopts the social network analysis method used in previous studies (2) to examine the trade network of TCM products. On the one hand, the scope of application of social network analysis approach is expanded. On the other hand, this method enables analyzing the current status of the TCM trade network composed of various trading countries or regions in a relatively scientific manner.

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

All authors undertook research, writing, and review tasks throughout this study. All authors have read and agreed to the published version of the manuscript.

FUNDING

This work was supported by the Major Program of the National Social Science Foundation of China [Grant Number 20&ZD124], the National Social Science Foundation of China [Grant Number 21CJY024], and the National Natural Science Foundation of China [Grant Numbers 72174180, 72074195, 71973129, 72072162, and 71773115].

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frontiers | Frontiers in Public Health

HYPOTHESIS AND THEORY
published: 11 May 2022
doi: 10.3389/fpubh.2022.873875

Innovation Elements, Incubation Capacity, and Incubation Performance in Biomedical Incubation Platforms: Moderating Role of Customized Services

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Biomedical incubation platforms make full use of innovation elements, constantly absorbing, integrating, and allocating various resources and innovating the incubation service mode, an important path to improving the performance of innovation incubation. Based on resource-based theory, network theory, and value chain theory, we proposed the conceptual model and research hypothesis for the relationship between innovation elements, incubation capacity, and innovation incubation performance in biomedical incubation platforms, with customized service as a moderating variable. The empirical results show that innovation elements have a significant positive impact on the improvement and transition of incubation capacity. Incubation capacity has a significant positive impact on innovation incubation performance in biomedical incubation platforms. Customized service plays a significant positive regulatory role between incubation capacity and innovation incubation performance in biomedical incubation platforms.

Keywords: biomedical incubation platform, innovation elements, incubation capacity, customized service, incubation performance

OPEN ACCESS

Edited by:
Fu-Sheng Tsai,
Cheng Shiu University, Taiwan

Reviewed by:
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Cheng Shiu University, Taiwan
Wei Xu,
Shenyang University of Chemical Technology, China

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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *11 February 2022*
Accepted: *05 April 2022*
Published: *11 May 2022*

Citation:
Jiang Q, Wang D, Wang Y and Wu B (2022) Innovation Elements, Incubation Capacity, and Incubation Performance in Biomedical Incubation Platforms: Moderating Role of Customized Services. Front. Public Health 10:873875. doi: 10.3389/fpubh.2022.873875

INTRODUCTION

The biomedical industry is a typical innovation-driven industry and the development and application of new products and technologies play a key role in the market competitiveness of enterprises. Biomedical incubation platforms incubate incubatees by providing a variety of entrepreneurial supports, including physical space, consulting services, financial support, and network connections (1), thereby helping them to better access the value-based resources necessary for survival and development and promoting the success rate of innovation and entrepreneurship. A biomedical incubation platform as a professional incubator can provide professional startup facilities, equipment, and technical services for startups. It is currently one of the main development directions for incubators aiming to achieve specialization. Biomedical incubation platforms have fallen into "core rigidity" and "capacity trap," along with frequent innovation iterations, intergenerational differences in incubation service functions, and diversified incubation needs. As a result, incubatees achieve little success in survival and development, capacity building, and incubation performance improvement. Innovation incubation aims to provide incubatees with intangible and higher value-added business service support (2). It seeks to guide the reconfiguration of incubation role functions and incubation links with industry chain construction as the main axis

through various specialized strategies such as sustainable development, collaborative innovation, and technology transfer. The focus of biomedical incubation platforms on innovation elements has great practical significance for strengthening incubation capacity, improving incubation functions, and enhancing incubation performance.

Guided by resource-based theory, transaction cost theory, and social exchange theory, incubation platform research has focused on basic management functions such as basic services, performance evaluation, capacity enhancement, and service innovation as a resource-mediated broker. It has explored the impact mechanism of incubator performance enhancement at the micro level. Most researchers adopt the static perspective of various incubation target plans and incubation practice designs, ignoring the reality of resource mismatch in the innovation incubation process, whereby innovation elements are fragmented and scattered. Researchers have neglected the special characteristics derived from the incubation ecology of double embedding in positive externalities and the integration effect based on transaction costs and relationship values (3). Schwartz and Hornych (4) show that an industry focus can help incubation platforms to establish more specialized incubation management rules, create good synergies, and achieve an effective transfer of active knowledge and competitiveness to incubatees through peer-to-peer resource matching services, thereby improving incubation performance. Bruneel et al. (5) shows that the function and chronology of services provided by incubation platforms lead to generational differences and to differences in incubation functions and directions. According to strategic management theory, focusing on one or a few narrow market segments can achieve a sustainable competitive advantage. Incubation platforms obtain long-term incubation effects through the continuous strengthening of incubation functions such as industry focus, market focus, and network focus (6). This causes innovation incubation platforms to focus on the rational arrangement and design of innovation elements and promotes the clustering effect of multiple factors such as "government, industry, academia, research, users, and finance" to achieve increased innovation capacity (7). Therefore, the exploration of innovation incubation performance should be generalized by the intergenerational evolution of incubation platforms and categorized according to the different types of incubation platforms, value propositions, and incubation service functions.

Researchers have explored in-depth the mechanism of the influence of absorptive capacity, social capital, incubation platform control, network plurality, and innovation incubation performance from the perspective of power-change theory. However, most studies have explored the causal mechanism or boundary conditions of innovation incubation performance from a single perspective, ignoring the knowledge sourcing of innovation factor flow and allocation in the process of innovation incubation and the reality of organic integration and high synergy between the incubation platform's incubation capacity and external value-based resources. Therefore, this article constructs a conceptual model including innovation elements, incubation capacity, and innovation incubation performance of biomedical incubation platforms. It explores the mediating role of incubation capacity in the relationship between innovation elements and innovation incubation performance by using a structural equation model and examining the moderating role of customized services in the relationship between the incubation capacity and the innovation incubation performance of biomedical incubation platforms by using hierarchical regression analysis. This article aims to reveal the influence mechanism and the effectiveness mechanism of innovation factor focus in promoting advances in incubation capacity and enhancing the innovation incubation performance of biomedical incubation platforms. It aims to provide theoretical support and practical guidance for biomedical incubation platforms to enhance incubation performance and accelerate the growth of incubatees.

CONCEPT DEFINITION AND STUDY HYPOTHESIS

Innovation Elements

The composition of innovation factors mainly includes a simple two-dimensional classification taken from the direct factors of technology, capital, and human capital and the indirect factors of infrastructure, social environment, and macropolicies from the production factor perspective (8). It includes the main elements covering universities, institutions, and enterprises; resource elements such as information, knowledge, talents, and capital; and environmental elements such as internal hardware innovation environment and the external network innovation environment from a system and environment perspective (9). It also covers the three-dimensional structural elements of subject, support, and market (10) from the structure and function perspective. Integrating the above study foundation, the essential characteristics of biomedical incubation platforms, and the resource allocation characteristics of China's digital transformation context, we examined the connotation of innovation elements from the perspective of their roots and their essential factors. We concluded that innovation knowledge sources (11), incubation network environment (12), and value chain information (13) are the core elements that meet the characteristics of biomedical incubation platform and industry needs.

Innovation Knowledge Source

Innovation knowledge source is an important innovation element for science and technology enterprises. The high-tech characteristics of biomedical enterprises provide innovation knowledge source with a technological connotation. This connotation includes high-tech, scientific, and technological leaders, innovative creative thinking, and high-tech advanced medical equipment or instruments. The two main ways to obtain or contact innovative knowledge sources are to acquire external knowledge sources directly and to collaborate with organizations or individuals who have innovative knowledge sources. Zhang and Liu (14) explored the relationship between external innovation knowledge sources and absorptive capacity and breakthrough innovation performance and how fully

utilizing external innovation knowledge resources can enhance absorptive capacity and innovation performance (15). Hou et al. (16) pointed out that external knowledge sources can achieve knowledge accumulation and update knowledge stock by continuously creating new knowledge through external cooperation, thereby effectively enhancing innovation performance (14). Incubated biomedical companies often find it difficult to achieve breakthrough innovation due to the lack of key technologies, scientific and technological talents, and backward medical equipment or instruments, forcing incubated biomedical companies to acquire knowledge of medical science and technology innovation. The acquisition of innovative knowledge sources, such as technical reports, technology transfer, patent databases, university–enterprise cooperation, and cooperation with third-party research institutions, can promote the incubation capacity of biomedical incubation platforms and enhance technological innovation. In particular, scientific and technological innovation talents and patents are regarded as the most valuable innovative knowledge sources at the knowledge and technology levels. This is of great significance to the overall construction of biomedical incubation platforms. Therefore, the following hypotheses are proposed.

H1: There is a significant positive correlation between innovative knowledge sources and the incubation capacity of biomedical incubation platforms.

Incubation Network Environment

The biomedical incubation platform incubation network refers to the organization beyond the nodes constituted by the biomedical incubation platforms through building intra-organizational and cross-organizational cooperation interfaces (16). These interfaces are embedded in the socioeconomic environment. They are linked to other incubators, governments, markets, suppliers, financial institutions, universities, research institutes, and other behavioral nodes, whose networking function can effectively overcome the difficulties of resource element scarcity, reducing the costs of resource search negotiation (17). He et al. (18) argue that an organization's network is regarded as a relationship of mutually beneficial and interdependent organizational forms, in which suppliers or partners provide resources to jointly design or jointly produce innovative services and products (19). The incubation network environment is specifically subdivided into government policy support, external capital investment, organizational and cultural atmosphere, infrastructure environment, and incubation network scale. Sun and Li (20) point out that network size reflects the richness of resource elements and that the growth of network size will prompt the incubation platform to improve its self-incubation capacity, thereby enhancing the market discourse and innovation incubation performance of the incubation platform (18). Zhao et al. argue that incubation platform networks break the traditional organizational boundaries and geographical restrictions by building new information service platforms and various incubation public service platforms to help incubatees integrate various innovation resources and realize the integration and distribution of incubation resources, thereby improving incubation performance (20). Gao et al. argue that incubation platforms provide incubatees with an effective mechanism to create, complement, and eventually commercialize proprietary knowledge through customer interface (supply side of innovation) and market interface (demand side of innovation) activities, connecting and leveraging international networks of knowledge creation and knowledge application, and breaking the boundaries of interorganizational and international knowledge flows (21). Biomedical incubation platforms focus on building an incubation network environment that is conducive to the co-evolution of themselves and their incubatees and to the improvement of innovation incubation performance. Therefore, the following hypothesis is proposed:

H2: There is a significant positive correlation between the incubation network environment of biomedical incubation platforms and incubation capacity.

Value Chain Information

The value chain information of biomedical incubation platforms refers to the information resources attached to the value chain activities, the main ways in which biomedical incubation platforms and incubatees break through organizational boundary restrictions to obtain significant external information and knowledge resources. Value chains provide an effective way for enterprises to acquire new knowledge and technology, to extract core knowledge and key technologies through organizational learning, to form strategic alliances, and to engage in other means of enhancing information and innovation capabilities (22). The amount of information provided by customers or suppliers through working relationships can increase the effectiveness of conscious and deliberate learning mechanisms (23). Lau and Lo argue that value chain information is the main way for firms to obtain information about innovation that contributes to their resource and knowledge base (24). Jiang and Liu (25) pointed out that value chain information has different source paths and that incubatees need to resource patchwork value chain information from divergent sources through exploratory learning to make it a directly usable isomorphic resource. Horizontal and vertical cooperation in the value chain can provide technical knowledge and market resources for firms, thereby enhancing their service capabilities and integrated functions (25). Biomedical incubation platforms use their own dual learning to form isomorphic resources from different sources of value chain information through decoding, encoding, transferring, and innovating to embed the incubation processes directly. Therefore, the following hypothesis is proposed:

H3: There is a significant positive correlation between value chain information and the incubation capacity of biomedical incubation platforms.

Incubation Capacity

Incubation capability is the core competitiveness of a biomedical incubation platform. It consists of incubatees' self-incubation capabilities, which is the reflection of the comprehensive service capability of a biomedical incubation platform to incubate enterprises and its own growth capability (26).

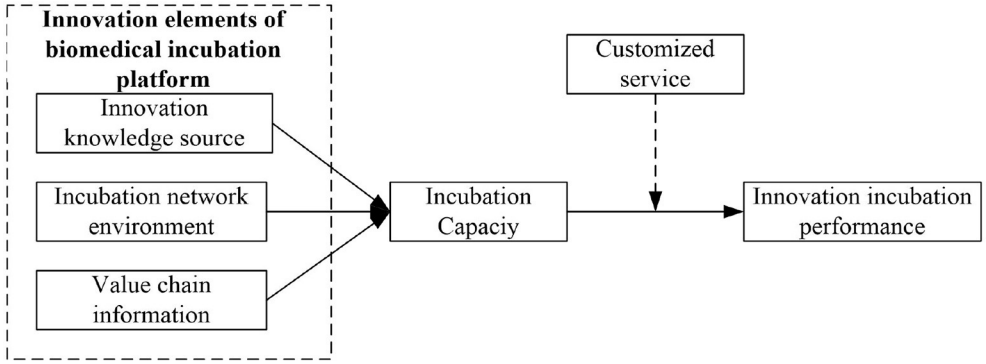


FIGURE 1 | Conceptual model.

Colombo and Delmastro (27) showed that the capabilities of incubation platforms, such as talent pool, incubation experience, collaborative activities, innovation activities, and financial support, have a significant impact on the entrepreneurial performance of incubatees (28). Tian et al. (29) concluded that the innovation capabilities of incubation platforms facilitate the integration and utilization of existing technological know-how by incubatees and enhances incubation performance (30). Jiang and Tang (31) showed that there is a significant positive effect between the dynamic learning capacity of incubation platforms and innovation incubation performance (32). Jiang et al. argue that incubation platforms use network orchestration capabilities to enable the development of value platforms and subsequently improve innovation incubation performance (27). Wang et al. (33) showed that incubation capabilities can help incubatees to make better use of newly acquired knowledge and facilitate effective decision-making based on acquired new knowledge (29). Therefore, the following hypothesis is proposed:

H4: There is a significant positive correlation between incubation capacity and innovation incubation performance of biomedical incubation platforms.

Moderating Effect of Customized Services

The term customized service means that the incubation platform provides peer-to-peer professional incubation services in response to the actual conditions and heterogeneous needs of incubatees at the growth stage (31). Service customization plays the role of high-quality endorser and driver, providing customized services. By "bundling-related resources," it can achieve excellent customer value and reduce resource costs (34). In the context of the platform economy, biomedical incubation platforms continuously allocate priority resources to provide customized services to incubatees. They connect with external entities to carry out integrated customized services to meet the different needs of incubatees. This improves the incubation capacity of biomedical incubation platforms and accelerate the growth of incubatees, thereby enhancing the innovation incubation performance of biomedical incubation platforms (33). Zhang and Xiang (35) argued that customized knowledge-based services help supply and demand subjects form an interactive innovation interface, enhance the trust mechanism between collaborators, improve innovation capacity and service performance, and realize the dual value co-creation of system coupling and process coupling in the process of providing customized services in the areas of sales, consulting, alliance, and assistance (36). Biomedical incubation platforms provide peer-to-peer specialized services for incubatees in the complex situation of policy crossover and environment, rapidly improving incubation capacity and incubation quality. Therefore, the following hypothesis is proposed:

H5: Customized services have a significant positive moderating effect between the incubation capacity and innovation incubation performance of biomedical incubation platforms.

Figure 1 shows the conceptual model of this article.

RESEARCH METHODOLOGY

Data Collection

In this article, we study the influence of innovation elements and incubation capacity on the innovation incubation performance of biomedical incubation platforms. The sample is selected from incubation platforms such as biomedical industrial parks, incubators, and crowdsourcing spaces at or above provincial level as the survey objects. The Coronavirus disease 2019 (COVID-19) pandemic affected data collection. The data were obtained mainly through online questionnaires and video conference interviews with more than 10 regionally representative biomedical incubation platforms. The quality of data completion was ensured by arranging that the questionnaires were filled out anonymously by incubatee executives who were connected to the incubators and had a good grasp of the companies' innovation incubation. A declaration was made that the survey was intended for academic study and an undertaking was given promising the confidentiality of the questionnaires. From June to October 2021, 500 study questionnaires were distributed through email, WeChat, and other communication methods. A total of 358 questionnaires

TABLE 1 | Summary table of descriptive statistics.

Variables	M	SD	Skewness	Kurtosis	1	2	3	4	5	6
Innovation knowledge sources	3.6141	1.0869	−0.546	−0.79	1					
Incubation network environment	3.7430	0.9732	−1.050	1.072	0.565**	1				
Value chain information	3.6406	1.1270	−1.101	0.449	0.513**	0.484*	1			
Incubation capacity	3.6430	1.1179	−0.938	0.137	0.452**	0.458**	0.443**	1		
Customized services	3.6508	1.0812	−1.081	0.457	0.111**	0.107**	0.121**	0.452**	1	
Innovation Incubation Performance	3.6273	1.0527	−0.650	0.306	0.343**	0.288**	0.344**	0.337**	0.344**	1

*Denotes $p < 0.05$; **Denotes $p < 0.01$.

were collected, of which 38 questionnaires were invalid, leaving 320 valid questionnaires.

Variable Measurement

The variables in this study were measured on a five-point Likert scale, with 1–5 indicating "totally disagree" to "totally agree." The operationalized definitions and measurements of each variable were developed, designed, and improved based on relevant previous results.

Drawing on the study results of Zhou et al. (37) and Jiang et al. (25, 38), four scales were used to measure innovation knowledge sources: (i) acquiring high technology by incubation platform, (ii) signing up technology leaders by incubation platform, (iii) acquiring innovative creative thinking, and (iv) acquiring other innovative knowledge by incubation platform.

Drawing on the study results of Li et al. (39), four scales are used to measure the incubation network environment: (i) incubation platforms receive government policy support, (ii) incubation platforms improve organizational culture, (iii) incubation platforms enhance the infrastructure environment, and (iv) incubation platforms expand the incubation network scale.

Drawing on the study results of Guo et al. (13), Lau and Lo, (23), and Liu (24), and others, four scales are used to measure the value chain information: (i) the incubation platform gets technical information resources, (ii) the incubation platform gets market information resources, (iii) the incubation platform gets innovation information resources, and (iv) the incubation platform gets other information resources.

Drawing on the study results of Zhao et al. (35) and Sun and Li (40), four scales are used to measure the incubation capacity: (i) incubation platform's improved ability to cultivate incubatees, (ii) incubation platform's improved ability to provide comprehensive services to incubatees, (iii) incubation platform's improved ability to self-incubate, and (iv) incubation platform's enhancement of strategic awareness.

Drawing on the study results of Jiang et al. (27), four scales are used to measure customized services: (i) providing heterogeneous incubation services for incubatees based on their own resources, (ii) using relationship network resources to provide heterogeneous incubation services for incubatees, (iii) providing a docking place for incubatees and the two parties that can provide heterogeneous incubation services for them, and (iv) providing heterogeneous incubation services for incubatees in other ways that provide heterogeneous incubation services for incubatees.

Drawing on the study results of Tang et al. (41), four scales were used to measure the innovation incubation performance: (i) good growth of incubated enterprises, (ii) improvement of incubated enterprises' technological innovation capacity, (iii) good transformation of incubated enterprises' technological achievements, and (iv) significant improvement of incubated enterprises' graduation rate.

DATA ANALYSIS AND RESULTS

Descriptive Statistical Analysis

Table 1 lists the mean, SD, skewness, kurtosis, and the Pearson's correlation coefficient of innovation knowledge source, incubation network environment, value chain information, incubation capacity, customized service, and innovation incubation performance. The formal sample results in **Table 3** show that the means for each question item range from 3.6141 to 3.7430 and the SDs range from 0.9732 to 1.1270. The skewness ranges from −1.101 to −0.546 and the kurtosis ranges from −0.790 to 1.072. The skewness and kurtosis satisfy the conditions of normal distribution, indicating that these 25 questions obey normal distribution. The correlation coefficients of innovation knowledge source, incubation network environment, and value chain information with incubation capacity are 0.452, 0.458, and 0.443, respectively. The correlation coefficients of incubation capacity and customized services are 0.452. The correlation coefficient of customized services and innovation incubation performance is 0.344. They are all significantly positively correlated at the 0.01 level. The correlation coefficients are all <0.7; there is no covariance. The data recovered from the questionnaire can be directly used in statistical analysis tests such as reliability analysis and structural equation model testing.

Reliability and Validity

In this study, the reliability and validity of the sample data were verified using Cronbach's α coefficients, combined reliability (CR), and average variance extracted (AVE) to ensure the authenticity and reliability of data analysis results. **Table 2** presents the results of the reliability and validity tests for each variable. The Cronbach's α coefficients for innovation knowledge source, incubation network environment, value chain information, incubation capacity, customized services, and

TABLE 2 | Reliability and validity analysis results.

Variable Variable	Number of items	Cronbach's alpha	CR CR	AVE AVE
Innovation knowledge source	4	0.864	0.850	0.587
Incubation network environment	4	0.895	0.877	0.641
Value chain information	4	0.897	0.883	0.654
Incubation capacity	4	0.924	0.887	0.663
Customized services	4	0.899	0.908	0.712
Innovation incubation performance	4	0.953	0.942	0.803

CR >0.6, AVE >0.5.

TABLE 3 | Structural equation model fit metrics.

Fitting index	Acceptable range	Measured value
CMIN		318.202
DF		163
CMIN/DF	1–3	1.952
GFI	>0.8, acceptable >0.9, good fit	0.913
AGFI	>0.8, acceptable >0.9, good fit	0.888
CFI	>0.9	0.969
RMSEA	<0.08	0.055

innovation incubation performance are 0.864, 0.895, 0.897, 0.924, 0.899, and 0.953. They are all >0.7. The CR is >0.8 and <1. The AVE is >0.5. The results indicate that all the dimensions of the study questionnaire have good reliability and validity.

Structural Equation Modeling Analysis

Using Amos version 23.0 to perform structural equation modeling (SEM) analysis, as shown in **Table 3**, CMIN/DF is 1.952, which is between the criteria of 1–3. GFI and CFI are greater than the discriminant criteria of 0.9. RMSEA is 0.055, which is <0.08. AGFI is 0.888, which is >0.8 and slightly <0.9, in line with the discriminant acceptance range. Therefore, the SEM model can be considered to have a good fit.

Table 4 shows that innovative knowledge sources have a significant positive effect on incubation capacity ($\beta = 0.302$, $p < 0.01$), indicating that the richer the innovation knowledge sources, the stronger the incubation capacity, thereby verifying hypothesis 1; incubation network environment has a significant positive effect on incubation capacity ($\beta = 0.256$, $p < 0.01$), indicating that the better the incubation network environment, the stronger the incubation capacity, thereby verifying hypothesis 2; value chain information has a significant positive effect on incubation capacity ($\beta = 0.249$, $p < 0.001$), indicating that the more value chain information is available, the stronger the incubation capacity, thereby verifying hypothesis 3; incubation capacity has a significant positive effect on innovation incubation performance ($\beta = 0.322$, $p < 0.001$), indicating that the stronger the incubation capacity of the biomedical incubation platform, the more significant the innovation incubation performance, thereby verifying hypothesis 4.

Test for Moderating Effect of Customized Services

Three-step hierarchical regression analysis sets the independent variable as incubation capacity; the dependent variable is set as innovation incubation performance and the interaction term of "incubation capacity × customized service" is added. **Table 5** shows the results of the moderating effect test, R2 is 0.113, 0.159, and 0.169 and the regression coefficients are significant. Therefore, customization services have a positive moderating effect on the effect of incubation capacity on innovation incubation performance, thereby verifying hypothesis 5.

CONCLUSION AND IMPLICATIONS

In the innovation incubation process of biomedical incubation platforms, innovation elements (innovation knowledge source, incubation network environment, and value chain information) have a significant positive impact on the innovation incubation performance of biomedical incubation platforms through the mediating role of incubation capacity. Customized services play a significant moderating role between incubation capacity and innovation incubation performance of biomedical incubation platforms. All five hypotheses were verified. The findings of this article have good theoretical reference significance and practical value for the focus of biomedical incubation platforms on the multiple innovation elements and their effective allocation in the incubation process and the improvement of innovation incubation performance of biomedical incubation platforms.

(1) Innovation elements (innovation knowledge source, incubation network environment, and value chain information) have a significant positive impact on incubation capacity. Incubation capacity as a mediating variable has a significant positive impact on the innovation incubation performance of biomedical incubation platforms. Biomedical incubation platforms directly improve innovation incubation performance by focusing on innovation elements in their operation and management practices. The focus of three innovation elements positively contributes to the survival rate and the growth status of incubatees, the cultivation of incubatees' scientific and technological innovation capabilities, the transformation of scientific and technological achievements, and the graduation rate of incubatees.

First, social capital, good entrepreneurial opportunities, and highly cooperative teams were viewed as the most important factors for entrepreneurship in China (42). Biomedical incubation platforms enhance innovation incubation performance by focusing on external sources of innovation knowledge such as focusing on biomedical R&D and innovation with organizations or individuals with source knowledge such as universities, key research institutes, key state laboratories, high-tech enterprises, advanced equipment manufacturing enterprises, and leading scientific and technological talents in the form of direct reading or collaborative cooperation and

TABLE 4 | Path coefficients.

Path relation			Standardization factor	SE	CR	P
Incubation capacity	←	Innovative knowledge source	0.302	0.097	3.115	0.002
Incubation capacity	←	Incubation network environment	0.256	0.089	2.890	0.004
Incubation capacity	←	Value chain information	0.249	0.072	3.473	***
Innovation incubation performance	←	Incubation capacity	0.322	0.052	6.241	***

TABLE 5 | Moderating effect of customization services.

	Innovation incubation performance		
	Step 1	Step 2	Step 3
Independent variables			
Incubation capacity	0.317***	0.214***	0.245***
Adjustment variables			
Customized services		0.231***	0.260***
Interaction items			
Incubation capacity*Customization services			0.067***
R2	0.113	0.159	0.169
ΔR2	0.113	0.046	0.009
ΔF	40.636***	17.394***	3.550***

*Denotes $p < 0.05$; **Denotes $p < 0.01$; Denotes $p < 0.001$.

innovation, to continuously improve incubation capacity and to enhance innovation incubation performance.

Second, biomedical incubation platforms grasp the development direction of innovation and entrepreneurship policies, focus on building an ecosystem platform for an incubation network, and build broad open-source incubation platforms by creating a harmonious organizational and cultural atmosphere for biomedical incubation platforms, incubatees, and multiple external subjects. These actions will expand the scale of the incubation network and will attract capital and technology from external subjects to create good incubation platforms. Technology and other factors create a good resource environment for the incubation network, continuously improving the incubation capacity and improving innovation incubation performance.

Third, biomedical incubation platforms and incubatees obtain a large number of external information resources through the value chain to help them to break through the organizational boundary restrictions in business management practices and use diverse information resources such as technical information, market information, innovation information, and other kinds of information resources to respond appropriately to the challenges brought by fierce market competition and continuous development. Therefore, during the operation and management of biomedical incubation platforms, managers should strengthen the strategic awareness of innovation element acquisition and continuously strengthen the importance of the innovation element in biomedical incubation platform incubation capacity improvement. This would greatly enhance the incubation capacity and the comprehensive service capacity of incubated enterprises. It would also improve biomedical incubation platforms' own incubation capacity and promote decision-makers' management and innovation resources to compete for strategic awareness. Improvements in these aspects are essentially incubation capacity improvements.

(2) Customized services have a significant moderating effect between incubation capacity and innovation incubation performance. The higher level of customization services in the biomedical incubation platform is conducive to improving the range of incubation capacity, implying a greater contribution to innovation incubation performance. With high incubation capacity, a biomedical incubation platform can provide customized services to incubatees according to their growth stages and heterogeneous needs, thereby regulating the relationship between incubation capacity and innovation incubation performance and realizing the path of innovation incubation performance improvement mediated by incubation capacity. Customized services, as a moderating variable between incubation capacity and innovation incubation performance, work in two main ways. First, the biomedical incubation platform uses implicit knowledge and its a priori resource advantages to the full to provide order-based incubation services to meet the real needs of incubatees. Second, the biomedical incubation platform builds an incubation network ecosystem platform with external network subjects through customer interface, market interface, and technology interface activities, attracting multiple subjects to participate in solving incubatees' incubation problems with the incubation platform, motivating incubation parties to use the incubation platform as an interface to achieve knowledge interaction, and realize customized needs and services.

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/s.

ETHICS STATEMENT

Approved by the Scientific Research Office of Sanya University, this article named Innovation Elements, Incubation Capacity, and Incubation Performance in Biomedical Incubation Platform: Moderating Role of Customized Services, written by Jiang

Qian's research group, aims to illustrate the internal mechanism and effect of how innovation elements, incubation capability, and other variables affect the performance of innovation incubation on biomedical incubation platforms. The research purpose, research plan, research method, research content, and implementation process of this study all meet the relevant ethical requirements of Sanya University. We give our permission for future studies based on our study and please ensure that any follow-up study is in strict accordance with our study plan.

AUTHOR CONTRIBUTIONS

QJ: paper design, data analysis, and article writing. DW: paper design and data collection. YFW: paper design and article instruction. BYW: data analysis. All authors contributed to the article and approved the submitted version.

ACKNOWLEDGMENTS

The study on which this article is based was partly enabled through the National Social Science Foundation of China: Research on Platform-led Enterprise Digital Innovation Ecosystem and Value Co-creation from the Perspective of Dynamic Capabilities (No. 19BGL043), the Humanities and Social Sciences Research Planning Fund of the Ministry of Education: Research on Iterative Innovation and Strengthening Path of Super-module Platform Organization from the Perspective of Symbiotic Network (No. 20YJA630060), and the High-level Talents Program of Hainan Basic and Applied Basic Research Plan (Provincial Natural Science Foundation): Research on Cohesion Mechanism, Coupling Path and Application of Innovation Incubation of Science and Technology Business Incubators from the Perspective of Search-Learning (No. 2019RC255). These funding sources are gratefully acknowledged.

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ORIGINAL RESEARCH
published: 13 May 2022
doi: 10.3389/fpubh.2022.893199

The Effect of Nursing Internships on the Effectiveness of Implementing Information Technology Teaching

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In nursing education, the diversity of clinical scenarios is complex and dynamic, and it is a challenge for nursing students to learn this clinical knowledge in conventional teaching mechanisms. However, integrating information technology into teaching can promote diversity of learning environment. This study aimed to investigate the effectiveness of teaching mechanisms which combined clinical simulation scenario and Information Technology Integrated Instruction. This study applied innovative experimental teaching in medical–surgical and critical care nursing courses for nursing students in their fourth or fifth year at a five-year junior college. Instructional systems design was combined with clinical simulation scenarios and technology to develop multidimensional teaching strategies. Fifth-year students' overall OSCE mean score was considerably higher than that of fourth-year students; specifically, their scores on basic life support and care for subdural hemorrhage varied substantially. Compared with fourth-year students, fifth-year students performed considerably greater on situational awareness. The results of the present study can be used to develop nursing core competencies and improve the clinical care competency of nursing personnel.

Keywords: patient simulation, awareness, nursing education, information technology, OSCE

OPEN ACCESS

Edited by:
Fu-Sheng Tsai,
Cheng Shiu University, Taiwan

Reviewed by:
Shih-Chih Chen,
National Kaohsiung University of Science and Technology, Taiwan
Yi-Chun Du,
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Specialty section:
This article was submitted to Public Health Education and Promotion, a section of the journal Frontiers in Public Health

Received: *10 March 2022*
Accepted: *22 April 2022*
Published: *13 May 2022*

Citation:
Tseng L-P, Hou T-H, Huang L-P and Ou Y-K (2022) The Effect of Nursing Internships on the Effectiveness of Implementing Information Technology Teaching. Front. Public Health 10:893199. doi: 10.3389/fpubh.2022.893199

INTRODUCTION

Objective structured clinical examination (OSCE) is essentially a method for assessing learning outcomes by measuring clinical nursing ability and competence in clinical practice (1, 2). To conduct OSCE, a series of assessment stations is established, various health problems are simulated, and students' behavior and interaction with standardized patients are video recorded. Watson et al. (2) defined OSCE as an examination in which "students demonstrate their competence under a variety of simulated conditions." OSCE is effective for presenting learning outcomes and assessing students' clinical performance after graduation (1). Situational awareness (SA) describes individuals' perception, understanding, and subsequent predictions of what will happen in the surrounding environment. Specifically, people with high SA are aware of their surroundings and use that information to devise necessary plans or make decisions (3, 4). Projection is the highest level of SA and is achieved through personal understanding and the interpretation of perceptual clues as well as the expectation of future results (5, 6). Nursing care is a dynamic process, and Tower et al. (7) identified clinical decision-making as a paramount skill for nurses when caring

for patients. High SA helps nursing personnel make appropriate clinical decisions vital to patient care outcomes and safety. SA training for nursing personnel should be improved to help them achieve the highest level of SA and provide high-quality nursing care. The rapid development of information technology and prevalence of the internet have rendered information skills essential to student competitiveness (8). Innovative teaching methods such as online education, massive open online courses (MOOCs), and small private online courses (SPOCs) have been developed and employ various interactive educational software programs, high-fidelity equipment, teaching platforms, and sharing platforms that differ considerably from conventional teaching methods (9). The application of information integration has also changed how researchers examine learning methods (10, 11). The integration of technology into nursing education for the cultivation of professional nursing skills warrants further discussion.

This study applied innovative experimental teaching in medical–surgical and critical care nursing courses for nursing students in their fourth or fifth year at a 5-year junior college. Instructional systems design was combined with clinical simulation scenarios and technology to develop multidimensional teaching strategies. The flipped classroom approach and lesson plans based on clinical scenario simulations were applied to establish a reliable and valid OSCE scale for assessing nursing students' learning effectiveness, SA, and satisfaction with the proposed teaching methods. The findings may serve as a reference and highlight valuable implications for the development and application of future nursing education programs. The objectives of this study are as follows:

(1) To establish clinical simulation scenario lesson plans for medical and surgical nursing and integrate it with an OSCE, and then to verify the reliability and validity of the OSCE Checklist.
(2) Explore the difference between fourth- and fifth-year students in terms of OSCE scores following their participation in innovative teaching courses.
(3) Explore the difference between fourth- and fifth-year students in SA performance following their participation in innovative teaching courses.
(4) Explore fourth- and fifth-year students' satisfaction with the innovative teaching courses.

MATERIALS AND METHODS

Participants

Approval was obtained from the Institutional Review Board of St. Martin De Porres Hospital (No. 18B-12). Purposive sampling was conducted to select fourth- and fifth-year nursing students from a 5-year health care and management junior college in central Taiwan. Initially, 216 fourth-year nursing students and 74 fifth-year nursing students were recruited prior to the first semester of 2019. Researchers visited each class to explain the research plan, including the research objectives, research process, the rights of the participants, the implementation of the innovative courses, the teaching methods based on clinical scenario simulation and technology integration, administration of revised OSCE, and the required tasks. The students recruited for the study provided informed consent to human research after sufficient time for consideration. In total, 126 students constituted of 61 fourth-year and 65 fifth-year students participated in the study. Data was collected from March 1st, 2019 through to October 30th, 2020.

Research Tools

Medical and Surgical Nursing Courses

In the national examination, medical and surgical nursing is a core competency course and a major subject. This course cultivates students' professional and practical capacity in medical and surgical nursing—applying basic biomedical and scientific knowledge and nursing expertise they have learned; assessing and analyzing patients' physical, mental, spiritual, and sociocultural responses; suitably providing nursing measures; and accurately implementing and applying related techniques to clinical practices. This research implements innovative teaching methods, with teaching strategies including lectures, flipped classrooms, group discussions, information-technology based strategies, simulated scenarios and OSCE to cover the following eight topics of nursing care: body fluid and electrolyte imbalance, respiratory system, cardiovascular system, basic and advanced life support, shock, sepsis, and multiple organ failure, endocrine disorders, nervous system and urinary system.

Course Development and Design of Clinical Simulation Scenario Lesson Plans

There were two stages to develop course and design clinical simulation scenario lesson plans in the present study.

Stage 1: The medical–surgical and critical nursing courses integration.

The course development team, which constituted by nursing instructors, clinical nursing experts, and a clinical physician, convened several teaching discussion meetings to integrate teaching and learning mechanisms aimed at fourth-year students of a 5-year nursing program. They also incorporated scenario simulation with ITII (Information Technology Integrated Instruction) as the teaching strategy and conducted flipped classroom concepts and a revised OSCE to establish a critical nursing course. Traditional OSCE is usually conducted with rotations among multiple stations, while the three OSCE subjects tested in this study among 126 students, due to constraints in time, space and examiner availability were conducted by the examiners scoring the video recordings of students performing the tasks in the skills lab. The revised OSCE was more effective and fulfills its purpose than the traditional.

Stage 2: Scenario simulation teaching and clinical scenario teaching templates with the ADDIE model development.

(1) Scenario simulation teaching and clinical scenario teaching templates development

The present study introduced scenario simulation teaching into the lesson plans by referencing the Human Patient Simulation Scenario Development Patient Case Template (HPSSDPCT), the Template of Events for Applied and Critical Healthcare Simulation (TEACH Sim) (12) and the

ADDIE teaching design model which included analysis, design, development, implementation, and evaluation. The learning priorities, important events, and target responses were set by KSA (knowledge, skills, and attitude) which involved cognitive, psychomotor and affective domains.

(2) The clinical scenario simulation lesson plans design

The five topics was developed by course development team, included percutaneous transluminal coronary angioplasty (PTCA) and stent placement care for patients with acute myocardial infarction (AMI), basic life support (BLS) and operation of automated external defibrillator (AED), subdural hemorrhage (SDH) care, applications of the advanced Apollo Simulator in care for patients with septic shock, and acute respiratory distress syndrome (ARDS) care. They select the these five topics based on the importance and feasibility of the major teaching contents, and integrate the knowledge of other teaching contents into them as much as possible.Then, the final version was formed by conducting two pilot tests. Depending on the topic scenario, each plan was taught for 30–90 min.

OSCE Checklist Development

OSCE scores were used to evaluate student performance in this study and the test of face validity, content validity, and criterion validity were conduct after the first draft of the OSCE checklists.

(1) The First Draft of the Checklists

Because septic shock care and ARDS care require the use of advanced simulators and are therefore limited by equipment and this study's OSCE feasibility, these two scenarios were mainly taught and excluded from the OSCEs. In the end, the PTCA care for patients with AMI, BLS and AED operation, and SDH care were included in OSCE checklists. Checklist items were based on the actions in the process that students must complete; each checklist item was graded in 0 to 2 points (2 = fully completed, 1 = partially completed, 0 = not completed).

(2) Expert Content Validity Tests

The seventeen clinical experts and three fifth-year nursing students were invited to review the first draft of the three clinical scenario checklists and this study used the content validity index (CVI) as the measurement, each item of the evaluation survey was assigned 1–4 points on a 4-point Likert scale, where 1 = very appropriate, 2 = appropriate, 3 = inappropriate, and 4 = very inappropriate. The items were assessed based on expert appraisal, and the statistical method was based on the number of appropriate/very appropriate items divided by the total number of items; if the result was >0.80, the checklist was indicated to have a favorable validity index (13). The expert evaluations and opinions were organized into a summary table. Items that received 3 or 4 points were retained; items that received only 1 or 2 points or were determined to be unclear or badly worded were either revised or deleted after the expert opinions were discussed by the course development team. The CVI of PTCA care for patients with AMI was 0.981; 26 items were retained (four items were revised, one item was deleted). The CVI of BLS and AED was 0.987; 25 items were retained (three items were revised). The CVI of SDH care was 0.981; 13 items were retained (one item was revised). The OSCE checklists of all three simulation scenarios were graded based on a full score of 100 points.

(3) Reliability Testing

Four examiners used the Kendall coefficient of concordance to evaluate inter-rater reliability of checklists. For each topic, six students were sampled and the revised OSCE of the clinical scenario was held in the clinical skills center. Four nursing instructors evaluated the students' performances based on the three revised checklists. The Kendall coefficient of concordance values for the three clinical scenarios were 0.937, 0.896, and 0.965, suggesting high consistency; chi-square values were 18.731, 17.793, and 19.307 with p-values 0.000, 0.003, and 0.002, all smaller than 0.05. The performance of six students were significantly different, but the consistency in OSCE checklist evaluation was high among four instructors, indicating the revised OSCE checklist to be valid.

(4) Determination of SA Levels

Three SA levels were determined by 2 clinical design experts and three human-factors engineering experts and were integrated into OSCE checklists for assessment. Additionally, the present study also refered to Thompson et al. (3) and Tower et al. (7) for the applications of SA levels in medicine: the perception of cues from the setting, including patient information, electronic medical charts and information from other clinicians is important for processing of information and subsequent decision-making for the organization, rationalization and ordering of usuable data to construct an understanding of the present situation in the system to predict one or more possible occurrence of events to formulate appropriate responses and predict the next step. The first level (SA1) is perception level which included basic patient identification, interpretations, and skills operations. The second level (SA2) is comprehension level which included further treatment following observation, decisions and treatments based on SA1. The last level (SA3) is projection level which included proposal of precautions and health education, decisions and treatment based on SA2.

Information Technology Integrated Instruction Application

According to course progress and clinical scenario topics, seven information technology tools inclueded SPOCs, Zuvio, MOODLE teaching platform, LINE APP, High-fidelity wireless simulaton, Little Anne QCPR and AED trainer, were introduced in this study.

Satisfaction Survey

The student satisfaction survey was a structured survey modified with permission from a twenty-item survey by Tsai (14) with items relating to simulated clinical scenario, SPOCs and Zuvio rated by a five-point Likert scale to be submitted by nursing students anonymously for quantitative anlalyses.

TABLE 1 | Pearson correlation coefficients between three items of OSCE score and fourth-year and fifth-year students' scores on the summative critical care nursing assessment.

Variables	Fourth-year students ($n = 61$)		Fifth-year students ($n = 65$)	
	Pearson correlation coefficient	p-value (two-tailed)	Pearson correlation coefficient	p-value (two-tailed)
OSCE_AMI	0.587	0.000**	0.289	0.020*
OSCE_BLS	0.279	0.029*	0.303	0.014*
OSCE_SDH	0.471	0.000**	0.389	0.001**

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

TABLE 2 | Scores of fourth- and fifth-year students on the summative critical care nursing assessment and OSCE.

Variables	Fourth-year students ($n = 61$)		Fifth-year students ($n = 65$)		t-value	Degree of freedom	Significance (two-tailed)
	M	SD	M	SD			
Summative critical care nursing assessment	80.30	5.743	81.88	8.473	−1.219	124	0.225
Overall revised OSCE	230.18	26.890	263.43	17.062	−8.340	124	0.000**
OSCE_AMI	84.49	15.802	85.86	8.305	−0.614	124	0.540
OSCE_BLS	85.21	8.456	94.80	6.546	−7.141	124	0.000**
OSCE_SDH	60.57	11.566	82.62	10.087	−11.419	124	0.000**

**$p < 0.01$.

RESULTS

In total, 61 fourth-year and 65 fifth-year nursing students were recruited from a 5-year junior college. SPSS Statistics 23.0 was used for data compiling and analysis. Applied statistical methods consisted of descriptive statistics, independent sample t-tests, and Pearson's correlation coefficients. This section describes the reliability analysis of the scoring scales for the three OSCE dimensions, the effectiveness of the teaching methods according to clinical scenario simulation and technology integration, and student satisfaction with the innovative teaching methods.

Reliability Analysis of the Three OSCE Checklists

The consistency of the three OSCE checklists for the AMI, BLS, and SDH lesson plans were verified using Cronbach's α; the results were 0.61 for the AMI checklist, 0.80 for the BLS checklist, and 0.76 for the SDH checklist. The BLS and SDH checklists achieved high reliability.

Learning Performance of the Clinical Simulation Scenarios and ITII

Correlation Between Three Items of OSCE Score and Students' Scores on the Summative Critical Care Nursing Assessment

The correlation between summative evaluations of fourth and fifth year students and the revised OSCE scores, and to utilize the summative scores as performance indices for the OSCE subjects. The showed the results of fourth-year students showed that significant correlation between their summative critical care nursing assessment and revised OSCE score for AMI [$r(61) = 0.587$, $p = 0.000$], BLS [$r(61) = 0.279$, $p = 0.029$], SDH [$r(61) = 0.471$, $p = 0.000$]. The fifth-year students also showed that significant correlation between their summative critical care nursing assessment and revised OSCE score for AMI [$r(65) = 0.289$, $p = 0.020$], BLS [$r(65) = 0.303$, $p = 0.014$], SDH [$r(65) = 0.389$, $p = 0.001$]. Significant positive correlation between three items of OSCE score and scores on the summative critical care nursing assessment was found in the fourth-year and fifth-year students group (**Table 1**).

Difference Between Fourth- and Fifth-Year Students in Overall Revised OSCE Scores

The fifth-year students had completed a year-long clinical nursing internship, whereas the fourth-year students were preparing for the internship after the completion of the prior semester. The results of the independent sample t-test for the two groups are presented in **Table 2**. The results revealed that the scores of fourth- and fifth-year students on the summative critical care nursing assessment [$t(61.65) = -1.22$, $p = 0.225$] differed non-significantly. The slightly higher mean score for fifth-year students indicated that internship experience did not affect student performance in critical care nursing.The results showed that two groups of students differed significantly in overall revised OSCE scores [$t(61.65) = -8.34$, $p < 0.001$], and the fifth-year students had a total mean score 33 points higher than the fourth-year students did (**Table 2**).

Difference Between Fourth- and Fifth-Year Students in Scores on the Three OSCE Dimensions

The following results were obtained (**Table 1**): Fourth- and fifth-year students exhibited significant differences in BLS [$t(61.65) = -7.14$, $p < 0.001$] and SDH [$t(61.65) = -11.42$, $p < 0.001$].

TABLE 3 | Scores of fourth- and fifth-year students on the summative critical care nursing assessment and OSCE.

Variables	Fourth-year students ($n = 61$)		Fifth-year students ($n = 65$)		*t*-value	Degree of freedom	Significance (two-tailed)
	M	SD	M	SD			
AMI_SA1	23.92	4.394	26.14	1.657	−3.797	124	0.000**
AMI_SA2	30.98	6.896	29.49	4.272	1.469	124	0.144
AMI_SA3	29.46	7.435	30.88	4.498	−1.304	124	0.195
BLS_SA1	44.52	4.660	49.57	4.176	−6.407	124	0.000**
BLS_SA2	22.72	3.984	25.72	2.781	−4.929	124	0.000**
BLS_SA3	17.97	2.840	19.51	1.371	−3.915	124	0.000**
SDH_SA1	21.66	3.803	22.20	1.897	−1.026	124	0.307
SDH_SA2	25.89	5.404	25.92	5.048	−0.041	124	0.968
SDH_SA3	13.00	6.807	34.29	6.346	−18.172	124	0.000**

**$p < 0.01$.

TABLE 4 | SPOC completion rate statistics.

Course	Duration (min:s)	Completion rate for fourth-year students (%)	Completion rate for fifth-year students (%)
Basic hemodynamics	08:23	88.73	94.74
Overall revised OSCE	−8.340	124	0.000**
Anatomy and physiology of respiratory system and review	14:53	78.87	88.16
Chest x ray reading	18:04	77.46	78.95
Respiratory system treatment and care	18:44	73.24	77.63
EKG (1)	30:29	84.51	81.58
EKG (2)	22:25	74.65	78.95
EKG (3)	18:20	71.83	71.05
Medical–surgical nursing for coronary artery diseases	28:15	76.06	68.42
Medical–surgical nursing for AMI and review	17:35	66.20	61.84
BLS	44:25	70.42	61.84
Bonus: virtual reality for BLS and AMI	07:34	56.34	86.84
Wound care physiology and review	16:53	90.14	82.89
Fracture healing and care	15:45	80.28	84.21
Endocrine system and function	20:07	88.73	71.05
Physiology of the nervous system	27:27	83.10	60.53
Medical–surgical nursing for cerebrovascular diseases	27:37	80.28	89.47
Care for increased ICP	16:26	83.10	90.79
Abdominal physical assessment and common diseases	17:05	69.01	52.63
Gastrointestinal bleed care	11:22	77.46	48.68
Mean	20:10	77.53	75.80

**$p < 0.01$.

Compared with fourth-year students, fifth-year students scored 9.59 and 22.05 points higher for mean BLS and mean SDH, respectively. Despite the non-significant difference in AMI, fifth-year students still had a higher mean score for this dimension than fourth-year students did.

SA Differences Between Fourth- and Fifth-Year Students

All participants were assessed for SA1, SA2, and SA3 on the AMI, BLS, and SDH in the OSCE. The following results were obtained (**Table 3**): The two groups of students exhibited significant differences in AMI SA1 [$t(61.65) = -3.80$, $p < 0.001$]; SA1 [$t(61.65) = -6.41$, $p < 0.001$], SA2 [$t(61.65) = -4.93$, $p < 0.001$], BLS SA3 [$t(61.65) = -3.92$, $p = 0.001$], and SDH SA3 [$t(61.65) = -18.17$, $p < 0.001$]. The fifth-year students were higher scores than those of the fourth-year students, with a considerable 21.29-point difference in SDH SA3.

SPOC Completion Rate of Fourth- and Fifth-Year Students

In total, 20 SPOCs were established in this study, and students were able to preview lessons through the flipped classroom approach. The shortest and longest SPOCs, which

TABLE 5 | Independent sample *t*-test results for student satisfaction with innovative teaching.

Variables	Fourth-year students ($n = 61$)		Fifth-year students ($n = 65$)		*t*-value	Degree of freedom	Significance (two-tailed)
	M	SD	M	SD			
Scenario-based simulation teaching	4.667	0.385	4.468	0.712	1.926	122	0.056
SPOCs	4.667	0.460	4.459	0.723	1.909	122	0.059
Interactive educational software Zuvio	4.652	0.476	4.425	0.768	1.972	122	0.051

were entitled "Bonus: Virtual Reality for BLS and AMI" and "BLS," were 7 min and 34 s and 44 min and 25 s long, respectively. Most SPOCs were between 20 and 30 min, with a mean duration of 20 min and 10 s. The SPOC completion rate was calculated by the number of fourth or fifth year students online for the duration of the class divided by the total number of fourth or fifth year students recruited for this study, multiplied by one hundred percent.The difference of SPOC completion rates between fourth- and fifth-year students was non-significant (fourth year: 77.5%; fifth year: 75.8%). For the courses "Respiratory System and Review," "Bonus: Virtual Reality for BLS and AMI," and "Medical–Surgical Nursing for Cerebrovascular Diseases," students had higher completion rate than fourth-year students by 10–30%. For the courses "Endocrine System and Function," "Physiology of the Nervous System," "Abdominal Physical Assessment and Common Diseases," and "Gastrointestinal Bleed Care," the completion rate for fourth-year students was higher than that for fifth-year students by more than 20%. The SPOC completion rate statistics are presented in **Table 4**.

Student Satisfaction With Innovative Teaching Methods

The overall satisfaction scale used in the current study covered three dimensions, namely scenario-based simulation teaching, SPOCs, and the interactive educational software program Zuvio, and comprised 18 items. The overall satisfaction scale yielded a Cronbach's alpha of 0.984, indicating high reliability. The fourth- and fifth-year students varied in terms of items they were satisfied with and in satisfaction with the three dimensions covered by the scale.

The following results were obtained (**Table 5**): Our results showed no significant difference in satisfaction with scenario-based simulation teaching, SPOCs, or the interactive educational software program Zuvio, while the mean and standard deviation in fourth year students were higher than fifth year students. This result was likely caused by differences in group background and because fourth-year students were preparing for their internship and thus responded more positively to innovative teaching. The fifth-year students had already completed 1 year of clinical internship and were preparing for national entrance examinations; therefore, they were more committed to preparing for mock examinations in school than they were committed to studying for elective courses.

DISCUSSION AND CONCLUSION

Measurement Model Analysis

The results of this study exhibited that after participating in innovative teaching, the fourth- and fifth-year students exhibited significant differences in overall revised OSCE scores; accordingly, internship experience and other factors contributed to higher overall revised OSCE scores. Subsequently, the differences in scores between the two groups in the three OSCE dimensions were analyzed; significant differences were observed in the BLS and SDH scores. The mean BLS score of the fifth-year students was 9.59 points higher than that of the fourth-year students, and the two groups exhibited a considerable 22.05-point difference in SDH scores. Accordingly, internship experience and other factors related to learning experience contributed to higher scores on the three OSCE dimensions. According to the internal discussion of the course development group, SDH was the most difficult to learn, BLS required basic knowledge and skills, and AMI was of medium level of difficulty. The varying difficulty levels across OSCE might have caused the two groups to exhibit non-significant differences in the AMI dimension.

After participating in innovative teaching, the fourth- and fifth-year students exhibited significant differences in AMI SA1; BLS SA1, SA2, and SA3; and SDH SA3. Moreover, the fifth-year students had higher scores than the fourth-year students. Specifically, the two groups exhibited a considerable 21.29-point difference in SDH SA3. The high difficulty level of SDH might have caused a marked difference in scores between the two groups. Accordingly, internship experience and factors related to learning experience (e.g., higher seniority) greatly influenced the SA3 score for SDH, the most difficult subject. Bambini (15) proposed that the complexity of the simulation should be built according to the learner's level and match their competency. To construct the scenario lesson plans, which approximate clinical practices and complexity, the lesson planner should consider students' competency and complexity of materials simultaneously. Furthermore, the level of difficulty in the curriculum is related to the revised OSCE checklist, as seen in the significant difference between fourth and fifth year students in the total OSCE score and in SA 3. Recommendations for future development of the OSCE checklist based on simulation curricula include formulating program year- and subject-appropriate test items paired to the level of difficulty with SA 1, SA 2 and SA 3 in order to increase student-centered KSA.

In the satisfaction survey, fourth-year students had significantly higher scores than fifth-year students on three

OSCE dimensions and on overall satisfaction, which may be considered the overall evaluation of the proposed innovative teaching method. The different learning plans students had may have affected the evaluation results. The fourth-year students, who were preparing for their internships, exhibited high satisfaction with innovative teaching, especially in scenario-based simulation.

Fourth-year students had an overall satisfaction rate of 96.6% for SPOCs, which was higher than that of fifth-year students by 7.2%. The different learning plans students had may have resulted in the considerable difference between the two groups in terms of SPOC satisfaction rate. Specifically, fourth-year students were preparing for their internships, whereas fifth-year students were preparing for exams. Different learning goals between the two groups might have affected their satisfaction levels. Another possible factor influencing satisfaction is whether the SPOC recordings were attractive to the students. The overall optimization of online courses in the future may yield superior results. In terms of platform operation, both groups found Ewant easy to use and helpful for reviewing physical assessments, basic medicine, and medical–surgical nursing; both groups of students were highly satisfied with the application of SPOCs to autonomous learning and the use of the flipped classroom approach for course preview and review. Both the fourth- and fifth-year students had satisfaction rates of 98 and 89.5% toward Zuvio, respectively, and such high satisfaction may be attributable to the software's diverse functions. The fourth-year students had more experience using Zuvio, whereas the fifth-year students—who had just returned to school after a year-long internship—had little experience using it in class, despite its simple user interface. Whether usage frequency affected satisfaction requires further discussion.

Because of the increase in confirmed COVID-19 cases, numerous schools stopped offering onsite education and switched to remote learning (10). Previous literature has already reported the advantages of replacing MOOCs with SPOCs because there were some challenges of MOOCs (9, 16–18). The findings of this study demonstrated that SPOCs support the effectiveness of small-scale blended learning, and that this learning mechanism enhances the comprehensive and in-depth learning experiences for students while providing instructors with flexible and feasible teaching models simultaneously. Such model will provide a convenient way for instructors to understand students' learning needs and behaviors through learning hours, achievement rates, and formative (on-going feedback between students and instructors) and summative (tallying of test scores) evaluations. However, this study is an action research through a practicum course and we could not utilize only one mode of instruction while withholding others to protect the students' rights and interests. Future studies to compare between different modes of instructions such as ones in this study may be conducted in elective or non-core courses. Another limitation of the present study was that the students in the experimental group cannot prevent from Hawthorne effect since the research process cannot adopt a double-blind design in practical.

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/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by St. Martin De Porres Hospital (IRB No.: 18B-012 and Date of Approval: 2019/11/1). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

Y-KO and L-PT: study conception and design. L-PT: data collection. L-PT and L-PH: data analysis and interpretation. Y-KO, L-PT, and T-HH: drafting of the article and critical revision of the article. All authors have read and agreed to the published version of the manuscript.

FUNDING

This study was funded by the St. Martin De Porres Hospital (HR54-P1903) and the Allied Advanced Intelligent Biomedical Research Center (A21BRC) under the Higher Education Sprout Project of Ministry of Education.

ACKNOWLEDGMENTS

The authors are very grateful for the generous support from St. Martin De Porres Hospital and Chung-Jen Junior College of Nursing, Health Sciences and Management, as well as the assistance and co-operation of all the participants involved in the experiment. We would like to thank reviewers and the editor for their comments.

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frontiers | Frontiers in Public Health

ORIGINAL RESEARCH
published: 16 May 2022
doi: 10.3389/fpubh.2022.878515

Research on the Construction and Prediction of China's National Fitness Development Index System Under Social Reform

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Background: National fitness is a development plan formulated by China to promote people's participation in leisure and fitness, enhance people's physique, and realize the general goal of strengthening sports.

Methods: Based on combing the development process of China's national fitness after reform and opening up, using the improved "balanced scorecard" method, this article constructs an evaluation index system of the national fitness development index.

Results: The national fitness development index was established, including 4 first-level indicators, 14 second-level indicators, and 49 third-level indicators. It can calculate the national fitness development index with a total score of 100 points.

Conclusion: To verify the feasibility of the evaluation system, the goal current situation evaluation method is used to calculate the national fitness development index during the 14th Five Year Plan period based on the development of national fitness during the 13th Five Year Plan period to provide evaluation tools and theoretical reference for the development of national fitness in China.

Keywords: national fitness, evaluation index system, balanced scorecard, social reform, prediction

OPEN ACCESS

Edited by:
Fu-Sheng Tsai,
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Reviewed by:
Chunming Ye,
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Ruqia Shaikh,
Henan University, China

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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *18 February 2022*
Accepted: *14 March 2022*
Published: *16 May 2022*

Citation:
Liu Z, Zhang S, Li L, Hu B, Liu R, Zhao Z and Zhao Y (2022) Research on the Construction and Prediction of China's National Fitness Development Index System Under Social Reform. Front. Public Health 10:878515. doi: 10.3389/fpubh.2022.878515

INTRODUCTION

On October 20, 2014, The State Council of China issued several opinions on accelerating the development of the sports industry and promoting sports consumption, which clearly stated: "We must develop mass sports in an all-round way, constantly meet the growing demand of the people for sports, and make national fitness a national strategy (1)." The national fitness development of China is so far from the in-depth development stage into the optimization and upgrading stage (2). National fitness is a development plan formulated by China to promote leisure and fitness participation, enhance people's physique, improve people's health level, and realize the general goal of building a strong sports country (3). After years of efforts, the national fitness strategy has been deeply implemented, the level of public services has been significantly improved, and the proportion of people who often participate in physical exercise has reached 37.2%. At the same time, there are still some problems in the development of national fitness in China, such as the structural imbalance between supply

and demand of public services, the insufficient distribution of the role of the market mechanism, and the insufficient construction of standardization (4).

Against the historical background of the new era, China is at a historical moment of moving from a great sports country to a great sports country (5, 6). With "Healthy China 2030" as the blueprint, the national fitness campaign is widely promoted to improve the health of the whole people (7). The Chinese government regards the national fitness strategy as a sports industrial revolution and adopts a series of effective measures to develop the sports environment and improve the participation rate of national fitness (8). Public service facilities are the physical space of national fitness and constructing public sports facilities is the key content of national fitness (9). The research shows that more than half of the residents are satisfied with the current national fitness public service, but problems such as low standardization, unequalization of service, and lack of professional talents still exist (10). Equalization of national fitness public services is to ensure that all citizens enjoy equal opportunities for fitness services (11). With the improvement of people's living standards, the contradiction between people's growing demand for sports service and the relatively backward sports service is becoming increasingly prominent (12). The goal of "national fitness and urban integration" can coordinate the layout of urban and rural public sports resources and services and achieve the equalization of basic public services of national fitness for residents (13). Community is the basic carrier of urban public services, so we should strengthen the construction of fitness facilities in urban communities, improve the fitness literacy of drama titles, and integrate sports activities into people's daily life (14). The construction of a policy system focusing on national fitness can rely on the driving force behind the policy to promote the progress of national fitness in organizational structure, laws and regulations, personnel training, and other aspects. The research shows that there is an asymmetric mutualistic symbiotic relationship between national fitness and the sports industry for a long time (15). In developing countries, sports have made a significant contribution to improving people's wellbeing (16).

The construction of the evaluation system of national fitness, scholars from different dimensions is studied in "sports power construction program" as the basic framework, build the mass sports, competitive sports, sports industry, sports culture, sports diplomacy, security system, and negative indicators of seven dimensions in a new era of comprehensive evaluation index system of sports development (17). The mass sports evaluation index system takes the goal realization, the main aspect, the development foundation, and the support system as the system-level evaluation index (18). The local government national fitness public service performance evaluation system is composed of four dimensions: efficiency, quality, democracy, and responsiveness. Ningbo national fitness basic public service quality evaluation system is composed of public sports facilities quality, public sports service quality, fitness environment quality, affiliated sports facilities quality, and mass fitness service personnel quality (19).

The development of national fitness is related to the effective implementation of "sports power strategy" and "healthy China strategy." Existing studies lack a systematic and holistic development index evaluation system for national fitness, leading to the inability to quantify the development of national fitness, which is not conducive to scientific decision-making by government agencies. Therefore, by sorting out the development process of national fitness in China, this article understands the opportunities, problems, and requirements facing national fitness at present, and introduces the improved "balanced scorecard" based on policy documents, expert interviews, and relevant literature research. The establishment of the national fitness development index will evaluate the development of China's national fitness in a quantitative form for the first time. According to the index comparison, we can obtain the regional balanced development and growth of national fitness, to help government agencies, business entities, the public, and other stakeholders find the direction and ideas to improve and enhance national fitness.

OVERVIEW OF NATIONAL FITNESS IN CHINA

The Development of National Fitness

After China's reform and opening up, the development of national fitness has generally experienced three stages.

Full Start-Up Stage (1995–2008)

The relevant policy documents in the full start-up stage are shown in **Table 1**. In this stage, China's national fitness activities started in full swing, constantly improving the legal system and supporting facilities for national fitness, national fitness activities began to occupy an important position (20).

In-depth Development Stage (2009–2014)

The relevant policy documents in the In-depth Development Stage are shown in **Table 2**. The success of the Beijing Olympic Games not only stimulated the enthusiasm of the people all over the country for sports but also promoted the rapid development of China's national fitness cause. According to statistics, in this stage, China has issued 118 policy documents related to national fitness (21).

In this stage, China gradually from a sports country to a sports power, by promoting the development of the sports industry to promote national fitness activities, national fitness has become a national strategy.

Optimization and Upgrading Stage (2015–Present)

The relevant policy documents in the Optimization and Upgrading Stage are shown in **Table 3**. Since 2015, the construction of China's national fitness system has entered a stage of continuous optimization and upgrading.

In this stage, the construction of China's national fitness system tends to be improved. The state attaches great importance to national fitness activities, and national fitness has risen to a new height.

Analysis on Opportunities and Bottlenecks of National Fitness

At present, the development of national fitness is facing major opportunities. First, the development of cross-domain integration has created new opportunities for the development

TABLE 1 | Relevant contents of the full start-up stage of national fitness.

Time	Content	Issuing subject
1995.06.20	"Outline of the National Fitness Program"	The State Council
1995.08.29	"Sport Law of the PRC"	The National People's Congress
2002.07.22	"In the opinions on further strengthening and improving the new period sports work"	The State Council
2003.08.01	"Public Cultural and Sports Facilities Ordinance"	The State Council
2004.08.26	"Notice on Further Strengthening the Use and Management of Sports Lottery Public Welfare Fund for National Fitness"	SSAC
2007.05.14	"'National Fitness and Olympic Games' Series Activities"	SSAC
2008.12.15	"Strive to promote China from a big sports country to a powerful sports country"	Hu Jintao

TABLE 2 | Relevant contents of the in-depth development stage of national fitness.

Time	Content	Issuing subject
2009.10.01	"Regulations on National Fitness"	The State Council
2011.02.15	"National Fitness Program (2011–2015)"	The State Council
2011.04.29	"The 12th Five-Year Plan for the Development of Sports"	SSAC
2012.01.17	"Fifteen years of implementation of the Outline of the National Fitness Program"	SSAC
2013.12.16	"Measures for the Implementation of national Physical Training Standards"	SSAC
2014.01.04	"Opinions on Strengthening and Improving Mass Sports Work"	SSAC
2014.10.20	"The development of the sports industry to promote sports consumption"	The State Council

TABLE 3 | Relevant contents of national fitness optimization and upgrading stage.

Time	Content	Issuing subject
2015.11.16	"Remarkable results have been achieved in national fitness activities"	SSAC
2016.05.05	"The 13th Five-Year Plan for Sports Development"	SSAC
2016.06.23	"National Fitness Program (2011-2015)"	The State Council
2016.10.25	"Outline of the 'Healthy China 2030' "	The State Council
2017.08.28	"Take meeting people's fitness needs as the starting point of sports work"	Xi Jinping
2019.07.09	"Healthy China Action (2019-2030)"	National Health Commission
2019.08.10	"National fitness is more close to the people, more convenient and more popular"	General Office of the State Council
2019.09.24	"More than 400 million people often take part in physical exercise in China"	"70 years of sports in New China"
2020.10.29	"Proposal of the CPC Central Committee on formulating the 14th Five-Year Plan for National Economic and Social Development and long-range Targets for 2035"	19th CPC Central Committee
2021.08.13	"National Fitness Program (2021-2025)"	The State Council
2021.10.08	"Sports Development Plan of the 14th Five-year Plan"	SSAC

of national fitness, and the development concepts of "integration of sports and health," "integration of sports and education," and "combination of sports and tourism" have been gradually deepened. Second, the vigorous development of the social economy has injected impetus into national fitness. The growing diversified fitness needs of the people and the market-oriented operation of non-basic public sports services will promote the prosperity and development of national fitness. Third, the development of modern information technology empowers national fitness. With the rapid development of modern information technologies such as the Internet of things, big data, cloud computing, 5G, and AI, the development of national fitness has been given more possibilities.

The development of national fitness still needs to break through the following problems. First, the overall effect of national fitness needs to be improved. The gap in the development level of mass sports between urban and rural areas and between regions still exists. Second, there is an urgent need to realize the core leading transformation from government satisfaction to people's satisfaction in the performance management of national fitness services. Third, the integrated development ability and effect of national fitness need to be improved.

CONSTRUCTION OF NATIONAL FITNESS DEVELOPMENT INDEX EVALUATION SYSTEM

Screening and Modification of Index Evaluation Indicators

This article will introduce the idea of a "balanced scorecard" in the process of constructing the evaluation system of the national fitness development index. The improved "balanced scorecard" method is adopted to set up the index system from stakeholder dimension, financial dimension, learning and growth dimension, and internal process dimension, respectively, to comprehensively reflect the development of national fitness in China (22, 23). National fitness balanced scorecard model is shown in **Figure 1**.

This study focuses on the development of the four dimensions of national fitness during the 14th Five-year Plan period to ensure the comprehensiveness, consistency, and integrity of the index system. The improved Delphi method was adopted to screen the draft of the national fitness development index, and the final evaluation system was constructed by combining expert subjective judgment with objective data statistics (24). By designing the expert membership questionnaire of the national fitness development index evaluation system, the experts'

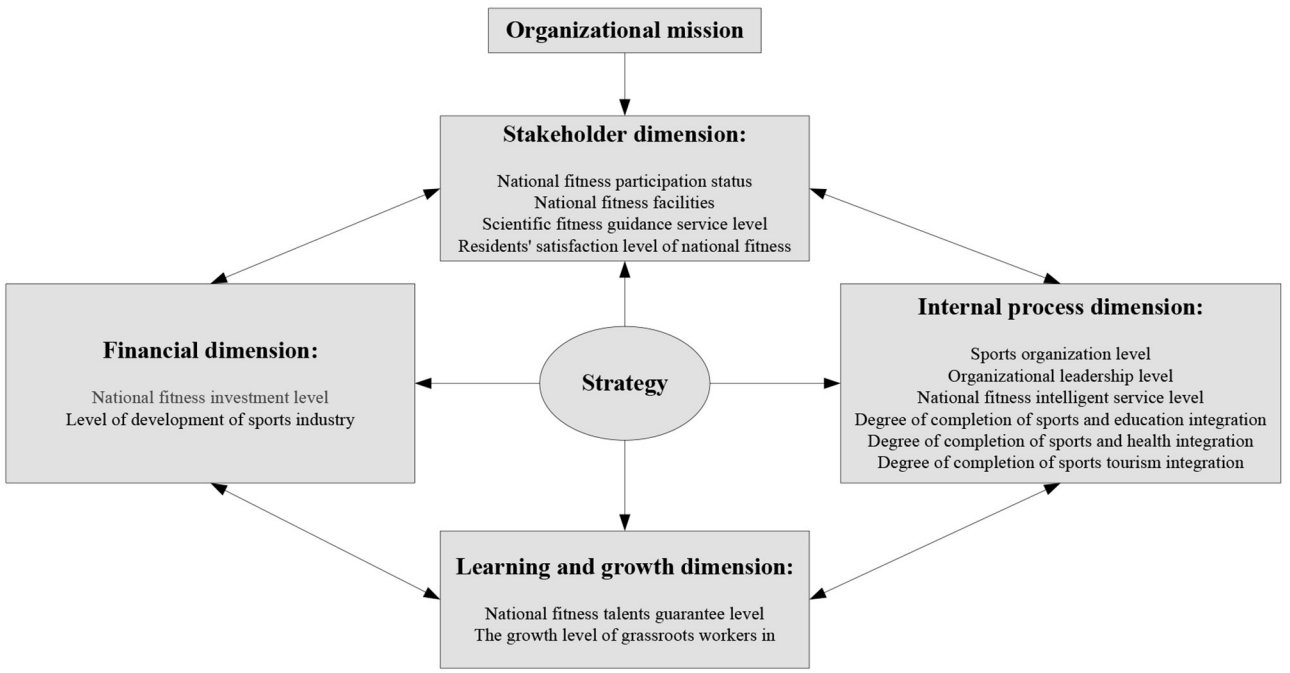


FIGURE 1 | National fitness balanced scorecard model.

opinions on the increase, deletion, and merger of indicators were obtained. The reliability and validity of the questionnaires were tested (25–27).

In the process of expert consultation, the questionnaire of "Expert membership degree of national fitness development index evaluation system construction" was distributed to the experts, and the experts were invited to judge the "rationality" of the specific measurement indicators in the evaluation system. "Rationality" refers to the importance of the indicator to the evaluation system. To facilitate quantitative analysis, 1–5 points are used, where 1 means "extremely unreasonable and should be removed," while 5 means "completely reasonable and should be retained." The corresponding evaluation results from 1 to 5 are positively increasing. In addition, experts were invited to put forward revised opinions and suggestions on the addition and deletion of measurement indicators. Stata 14 was used for data statistical processing, and the average, standard number, coefficient of variation, and coordination coefficient of each factor layer were calculated. The specific results are shown in **Table 4** (28, 29).

According to the experts' questionnaire feedback results and the current development of national fitness, the index system is modified (30–32). Finally, combined with many in-depth interviews with experts in the industry, referring to the previous scholars' research on the evaluation system development and combing the related policy documents and leaders' relevant statements (33, 34). After sorting out, the final results of the national fitness development index evaluation system include 4 first-level indicators, 14 second-level indicators, and 49 third-level indicators, as shown in **Table 5**.

National Fitness Development Index Evaluation Index Meaning

Stakeholder Dimension

The stakeholder dimension includes four secondary indicators, namely, participation status of national fitness, facilities supply of national fitness venues, scientific fitness guidance service level, and residents' satisfaction level of national fitness conditions.

The proportion of people who regularly take part in physical exercise is used to reflect the state of national fitness participation. Regular physical activity was defined as more than three times per week of moderate-intensity exercise lasting more than 30 min.

National fitness facilities include sports venues, fitness centers, school sports facilities, etc. The area of public sports venues per 10,000 people can reflect the scale of sports venues and facilities. The standard rate of school stadium facilities and equipment is the necessary condition and material guarantee to carry out normal physical education. The coverage rate of public fitness facilities and 15-min fitness circles in counties (cities, districts), towns (streets), and administrative villages (communities) can reflect the regional distribution of national fitness venues and ensure the demand of residents for fitness activities.

To improve the service level of scientific fitness guidance, it is related to the number of social sports instructors, sports volunteers, and national physical monitoring centers. Social sports instructors are those who provide voluntary service for national fitness to the public and obtain technical ratings. The National Fitness Monitoring Center is a non-profit organization engaged in various kinds of national fitness testing and provides the scientific basis for promoting the implementation of the national fitness plan. And "national student physical health

TABLE 4 | Statistical results of evaluation indicators at all levels.

Indicators	Mean	Standard deviation	Variable coefficient
Factor layer index ($W = 0.62$)			
Stakeholder dimension	4.62	0.11	0.26
Financial dimension	4.88	0.36	0.38
Learning and growth dimension	4.85	0.33	0.14
Internal process dimension	4.76	0.25	0.31
The secondary indicators ($W = 0.53$)			
National fitness participation status	5.00	0.00	0.00
National fitness facilities	4.85	0.38	0.14
Scientific fitness guidance service level	4.77	0.44	0.19
Residents' satisfaction level of national fitness	4.31	0.75	0.56
National fitness investment level	4.38	0.65	0.42
Level of development of sports industry	4.62	0.51	0.26
National fitness talents guarantee level	4.84	0.36	0.11
The growth level of grassroots workers in national fitness programs	3.77	0.73	0.53
Sports organization level	4.38	0.65	0.42
Organizational leadership level	4.69	0.48	0.23
National fitness intelligent service level	4.62	0.51	0.26
National fitness integration development level	3.38	0.87	0.76
Specific measurement index ($W = 0.47$)			
Proportion of people in the country who regularly take part in physical exercise	5.00	0.00	0.00
Every 10,000 people have a public sports area	4.92	0.28	0.07
The number of stadiums per 10,000 people	4.84	0.31	0.14
Every ten thousand people have parks, city square area	3.61	0.50	0.27
The number of fitness centers (community sports centers, fitness clubs, etc.) per 10,000 people	4.46	0.52	0.27
School sports facilities and equipment configuration up to standard rate	4.31	0.75	0.56
Opening rate of school sports facilities	4.38	0.77	0.59
Opening rate of public fitness venues	3.77	0.60	0.36
County (city, district) public fitness facilities and community 15-minute fitness circle coverage	5.00	0.00	0.00
Township (street) public fitness facilities and community 15-minute fitness circle coverage	4.69	0.48	0.23
The coverage rate of public fitness facilities and 15-minute fitness circles in administrative villages (communities)	4.07	0.64	0.41
The number of social sports instructors per 10,000 people	5.00	0.00	0.00
The number of sports volunteers per 10,000 people	3.46	0.78	0.60
The number of national fitness monitoring centers per 10,000 people	4.15	0.55	0.31
The proportion of urban and rural residents who have reached the national physical fitness measurement standard	4.85	0.38	0.14
The excellent rate of meeting the national physical and health standards of students	4.53	0.52	0.27
The daily amount of school sports activities for primary and middle school students	4.69	0.48	0.23
The number of extracurricular sports activities for primary and secondary school students every day	3.61	0.65	0.42
Residents' satisfaction with site facilities	4.77	0.44	0.19
Residents' satisfaction with fitness guidance	4.76	0.43	0.18
Residents' satisfaction with fitness activity organization	4.46	0.66	0.42
Per capita investment in fitness facilities	4.62	0.65	0.42
Proportion of sports consumption in per capita disposable income of residents	4.92	0.28	0.08
Per capita investment in fitness activities	3.38	0.87	0.76
Input into training of fitness instructor volunteers	3.46	0.66	0.47
The proportion of public welfare funds invested in sports lottery in national fitness funds	4.62	0.60	0.36
Sports investment accounted for the proportion of total social investment	4.08	0.49	0.24
Proportion of total size of sports industry in GDP	4.92	0.27	0.07
Proportion of sports goods and related products manufacturing in the total size of sports industry	4.23	0.83	0.69
Proportion of sports service industry in the total size of sports industry	4.08	0.64	0.41
The proportion of sports facilities construction in the total size of sports industry	3.63	0.49	0.26

(Continued)

TABLE 4 | Continued

Indicators	Mean	Standard deviation	Variable coefficient
Proportion of added value of competition performance industry	4.31	0.63	0.40
Proportion of added value of fitness leisure industry	4.35	0.52	0.23
Number of sports administrators	3.63	0.68	0.45
Number of sports industry employees	4.48	0.69	0.46
Degree of grass-roots staff involvement in decision-making	4.53	0.51	0.26
Job satisfaction of grass-roots staff	4.42	0.71	0.43
Basic level staff work autonomy degree	4.00	0.71	0.51
Number of training sessions for grass-roots staff	3.52	0.84	0.75
Work reward system for grass-roots staff	3.12	0.82	0.70
Number of grassroots sports organizations	3.38	0.87	0.76
Number of social sports organizations	4.69	0.48	0.23
Number of national fitness clubs	4.07	0.64	0.41
Number of national fitness sites in urban communities	3.77	0.60	0.36
The number of "national sports industry demonstration bases"	3.46	0.56	0.54
Proportion of cooperation between government sports organizations and social sports organizations	3.51	0.76	0.48
The proportion of regular activities carried out by grassroots social sports organizations	3.24	0.89	0.65
Number of joint meetings of national fitness work of people's governments at all levels	4.46	0.52	0.23
The proportion of non-government forces participating in the development of the public service system for national fitness	4.51	0.63	0.41
To track and evaluate the implementation of national fitness and supervise and guide the degree	3.61	0.54	0.25
Number of national fitness information service platforms established at provincial and municipal levels	4.31	0.63	0.39
Number of online and intelligent sports events	4.36	0.77	0.57
Degree of completion of sports and education integration	3.77	0.54	0.34
Degree of completion of body-health integration	3.40	0.73	0.53
Degree of completion of body and travel integration	3.12	0.85	0.79

standard" is specially used to evaluate the health status of students in school standards. Young people's sports activities are an important way to promote the healthy growth of young people. The participation of youth in national fitness was measured by the daily physical activity hours of primary and secondary school students in and out of school.

In addition, citizens' satisfaction with national fitness is mainly reflected in three aspects: venue facilities, fitness guidance, and activity organization.

Financial Dimension

The financial dimension of national fitness is reflected in the input level and output level of national fitness (the development level of national fitness).

The total scale of residents' sports consumption includes the service and life consumption of residents' national fitness, which can reflect whether the current national fitness service can meet the demand. To a certain extent, the per capita investment in fitness activities reflects the government's emphasis on national fitness. The public welfare fund of sports lottery is the main source of funds for fitness activities, which can support the construction of a large number of public service venues for national fitness and the holding of mass sports activities.

The output dimension of national fitness is mainly reflected by the current development level of national fitness. The industrial scale is an important index to measure the development of national fitness. The reasonable industrial structure is of great significance to promote the high-quality development of the national fitness industry. The added value of the sports industry includes the added value of sports goods and related products manufacturing, the added value of sports facilities construction, and added value of sports services. Among them, fitness, leisure, and competition performance are the core of the sports service industry and the main direction of national fitness industry development in the future.

Dimension of Learning and Growth

The dimensions of learning and growth of national fitness include the level of talent guarantee and the level of growth of grass-roots staff.

The number of employees and the number of industrial legal entities, respectively, reflect the capacity of the industry to absorb the employment population and the power of market subjects. The future development of national fitness is closely related to the participation of grassroots staff.

The level of grassroots staff's participation in decision-making, job satisfaction, and degree of autonomy can largely determine the promotion and implementation of national fitness among the masses.

Internal Process Dimension

The internal process dimension of national fitness represents the development capability of the national fitness industry, including the level of a sports organization, organization

TABLE 5 | Final results of national fitness development index evaluation system.

Level indicators	Secondary indicators	Tertiary indicators
Stakeholder dimension (A)	National fitness participation status (A1)	Proportion of people in the country who regularly take part in physical exercise (A11)
	National fitness facilities (A2)	Every 10,000 people have a public sports area (A21)
		The number of stadiums per 10,000 people (A22)
		The number of fitness centers (community sports centers, fitness clubs, etc.) per 10,000 people (A23)
		School sports facilities and equipment configuration up to standard rate (A24)
		County (city, district) public fitness facilities and community 15-minute fitness circle coverage (A25)
		Township (street) public fitness facilities and community 15-minute fitness circle coverage (A26)
		The coverage rate of public fitness facilities and 15-minute fitness circles in administrative villages (communities) (A27)
	Scientific fitness guidance service level (A3)	The number of social sports instructors per 10,000 people (A31)
		The number of sports volunteers per 10,000 people (A32)
		The number of national fitness monitoring centers per 10,000 people (A33)
		The proportion of urban and rural residents who have reached the national physical fitness measurement standard (A34)
		The excellent rate of meeting the national physical and health standards of students (A35)
		The daily amount of school sports activities for primary and middle school students (A36)
		The number of extracurricular sports activities for primary and secondary school students every day (A37)
	Residents' satisfaction level of national fitness (A4)	Residents' satisfaction with site facilities (A41)
		Residents' satisfaction with fitness guidance (A42)
		Residents' satisfaction with fitness activity organization (A43)
Financial dimension (B)	National fitness investment level (B1)	The total size of residents' sports consumption (B11)
		Per capita investment in fitness activities (B12)
		Sports lottery public welfare fund input (B13)
		Total financing of sports industry (B14)
	Level of development of sports industry (B2)	Total size of sports industry (B21)
		The proportion of added value of sports industry in GDP (B22)
		Sports goods and related products manufacturing added value (B23)
		Added value of sports service industry (B24)
		Added value of sports facilities construction industry (B25)
		Proportion of added value of competition performance industry (B26)
		Proportion of added value of fitness leisure industry (B27)
Learning and growth dimension (C)	National fitness talents guarantee level (C1)	Sports industry legal entity (C11)
		Number of sports industry employees (C12)
	The growth level of grassroots workers in (C2)	Degree of grass-roots staff involvement in decision-making (C21)
		Job satisfaction of grass-roots staff (C22)
		Basic level staff work autonomy degree (C23)
Internal process dimension (D)	Sports organization level (D1)	Number of social sports organizations (D11)
		Number of national fitness sites in urban communities (D12)
		The number of "national sports industry demonstration bases" (D13)
		Proportion of cooperation between government sports organizations and social sports organizations (D14)
		The proportion of regular activities carried out by grassroots social sports organizations (D15)
	Organizational leadership level (D2)	Number of joint meetings of national fitness work of people's governments at all levels (D21)
		The proportion of non-government forces participating in the development of the public service system for national fitness (D22)
	National fitness intelligent service level (D3)	Number of national fitness information service platforms established at provincial and municipal levels (D31)
		Number of online and intelligent sports events at the national level (D32)
	Degree of completion of sports and education integration (D4)	Number of sports traditional characteristic schools (D41)
		Number of national youth sports clubs (D42)

(Continued)

TABLE 5 | Continued

Level indicators	Secondary indicators	Tertiary indicators
	Degree of completion of sports and health integration (D5)	Number of sports rehabilitation centers (D51)
		Number of sports therapists (D52)
	Degree of completion of sports tourism integration (D6)	National Sports Tourism Demonstration base (D61)
		Market size of sports tourism industry(D62)

leadership, intelligent service, and integration with education, health, and tourism.

Social sports organizations refer to non-profit social organizations that carry out nationwide fitness and sports competition activities and improve the fitness level of the masses. Grassroots social sports organizations include government sports organizations and social sports organizations, and their participation ratio can show the current marketization level of national fitness. The national sports industry demonstration base is the starting point of the top-level design of national sports industry development and the benchmark of regional sports development.

The level of organization and leadership is reflected in the number of joint meetings of the national fitness work of people's governments at all levels and the proportion of the government absorbing social forces to participate in the national fitness construction work. The National Fitness Plan (2021–2025) points out that the national fitness service level should be promoted by establishing provincial and municipal information service platforms and carrying out online and intelligent sports events.

The integrated development of the national fitness industry includes the integration of physical education, physical health, and sports travel. The number of traditional sports characteristic schools and the number of national youth sports clubs can directly reflect the current development of sports and education integration. The transformation from sports medical integration to sports health integration, through the establishment of sports rehabilitation centers and the training of sports rehabilitation teachers to provide sports rehabilitation plans for patients with chronic diseases and improve the sports rehabilitation level of the whole society. Sports is an important resource to develop the tourism industry, and tourism is an important driving force to promote the sports industry. The number of national sports tourism demonstration bases and the market size of the sports tourism industry are adopted to represent the level of sports tourism integration.

EMPIRICAL STUDY

This article calculates the weight of each index through the analytic hierarchy process (AHP) by aiming at the index system of national fitness development. The corresponding data of the last 5 years were collected as the base data of the index system, and the target value of each index needed to be achieved in the end, and the interval reference standard of the national fitness evaluation system was established, to form a complete national fitness development index evaluation system. The evaluation system can be used to calculate the development index in the next 5 years, which can be used as a tool to measure the development of national fitness in China in the future.

Weight Calculation of National Fitness Development Index

The reasonable degree of weight setting will affect the objectivity and fairness of the results. In this study, experts were invited to score the weights, AHP was used to distinguish the weights of evaluation indexes, a hierarchical model was established according to the evaluation index system, and a judgment matrix was constructed. Finally, the corresponding weight coefficients of evaluation indexes at each level were obtained (**Figure 2**).

Interval Reference Standard of National Fitness Development Index Evaluation System

Taking the relevant data of the last 5 years as the base period data, the target value method is adopted to set the target data. In the evaluation of the national fitness development index, the index less than the base period is unqualified, the index greater than the target data is excellent, and the index between the two is qualified and good, respectively. Points 25, 50, 75, and 100 are awarded to unsatisfactory, acceptable, good, and excellent, respectively. The development of national fitness is a relative and dynamic stage process, so the development index is evaluated by selecting the goal-status evaluation method. National Fitness assessment index interval reference standard is shown in **Figure 3**. The symbol in **Figure 3** represents the evaluation index, which has been explained in **Table 5**.

For quantitative indicators, benchmarking method and local fitting method are, respectively, used to set standards. The benchmarking method is based directly on the target values of relevant national plans, programs, and opinions. Among them, the "14th Five-year Plan for Sports Development" and "National Fitness Plan (2021–2025)" are programmatic documents for national fitness and the most important basis for establishing a comprehensive evaluation system. Partial fitting method: for some indicators with no clear target value, collect official statistical data, functional department work reports, consult relevant personnel, count relevant data in the past, and calculate the target value of the required variable according to the growth rate.

The achievement evaluation of qualitative indicators is mainly based on the objectives and tasks in relevant documents and plans, and the rationality of the achievement standard of each evaluation indicator is scored by experts.

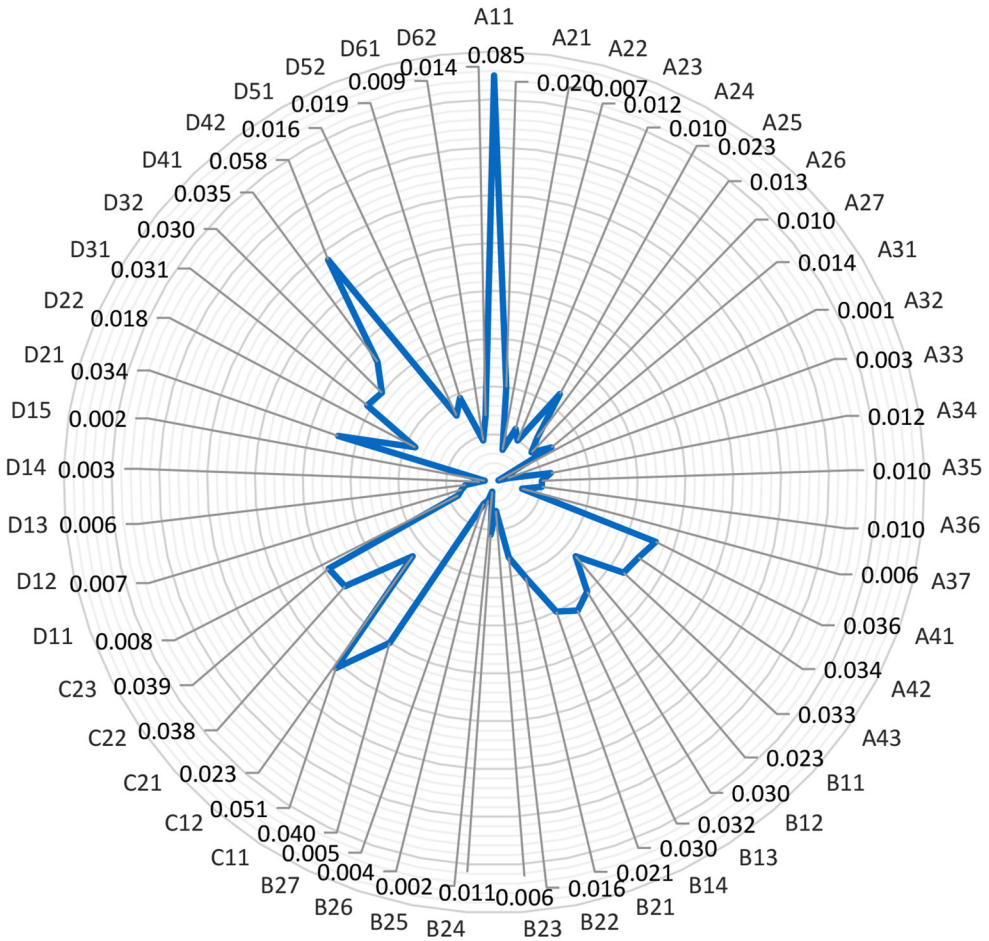


FIGURE 2 | The evaluation system of the national fitness development index and the weight value of each evaluation index.

Finally, the national fitness development index was established, including 4 first-level indicators, 14 second-level indicators, and 49 third-level indicators. It can calculate the national fitness development index with a total score of 100 points. Through index calculation, it can help government agencies, enterprises, the public, and other stakeholders to know the current development status and improvement direction of national fitness.

Result Analysis

Through the calculation of the weight of national fitness development indicators and the formulation of interval reference standards, it can be seen that the current development of national fitness should focus on the following areas:

Based on system construction, the legal environment for the implementation of the national strategy of national fitness is improved. The legislation and revision of laws and regulations in key areas of national fitness are strengthened, and a policy guarantee for the construction of a national fitness development index evaluation system is provided.

With resource integration as the core, the construction of a new pattern of coordinated governance of national fitness is deepened. The integrated development of national fitness is the general trend of the development of the times. The integration of national fitness with health, education, culture, science and technology, tourism, pension, and other fields is strengthened.

The main contradiction is taken as the starting point to make up for the shortboard of public service supply of national fitness. We should pay special attention to making up the shortcomings from the three aspects of the supply of national fitness venues and facilities, the supply of events and activities, and the supply of guidance services, to promote the equal development of public services for national fitness.

With the goal of enabling science and technology, the construction level of intelligent fitness services for the whole people is improved. The construction of an intelligent information platform for national fitness service supply is promoted, and the research on key technologies and products in the intelligent field of national fitness is strengthened.

Index		Unqualified	Qualified	Good	Excellent
A11	%	0 - 37.2	37.3 - 37.8	37.9 - 38.4	38.5 - 100
A21	hm^2	0 - 2.2	2.3 - 2.4	2.4 - 2.5	2.6 - +∞
A22	number	0 - 26.5	26.6 - 28.9	29.0 - 31.9	32.0 - +∞
A23	number	0 - 3	4-5	6-7	8 - +∞
A24	%	0 - 96.8	96.9 - 98.4	98.5． 99.9	100
A25	%	0 - 79	80 - 89	90 - 99	100
A26	%	0 - 49	50 - 69	70 - 99	100
A27	%	0 - 29	30 - 59	60 - 99	100
A31	number	0 - 18.6	18.7 - 20.1	20.2 - 21.5	21.6 - +∞
A32	number	0 - 21	22 - 25	26 - 29	30 - +∞
A33	%	0 - 90.0	90.1 - 90.7	90.8 - 91.4	91.5 - +∞
A34	%	0 - 48	49 - 51	52 - 54	55100
A35	hour	0 - 1	1.1 - 1.3	1.4 - 1.7	1.8 - +∞
A36	hour	0 - 0.8	0.8 - 1.2	1.3 - 1.5	1.6 - +∞
A37	%	0 - 25	26 - 50	51 - 75	76100
A41	%	0 - 25	26 - 50	51 - 75	76100
A42	%	0 - 25	26 - 50	51 - 75	76100
A43	个	0 - 0.7	0.8 - 1.5	1.6 - 2.0	2.1 - +∞
B11	个 trillion	0 - 1.5	1.6 - 2.1	2.2 - 2.7	2.8 - +∞
B12	个	0 - 35	36 - 40	41 - 45	46 - +∞
B13	个 billion	0 - 3.9	4.0 - 4.9	5.0 - 5.9	6.0 - +∞
B14	个 billion	0 - 40.0	40.1 - 50.0	50.1 - 60.0	60.1 - +∞
B21	个 trillion	0 - 2.9	3.0 - 3.9	4.0 - 4.9	5 - +∞
B22	%	0 - 1.1	1.2 - 1.5	1.6 - 1.9	2 - +∞
B23	个 billion	0 - 342.1	342.2 - 359.9	360.0 - 379.9	380.0 - +∞
B24	个 billion	0 - 761.5	761.6 - 779.9	780.0 - 799.9	800.0 - +∞
B25	个 billion	0 - 21.2	21.3 - 27.9	28.0 - 35.9	36.0 - +∞
B26	%	0 - 1.1	1.2 - 1.5	1.6 - 1.9	2.0 - +∞
B27	%	0 - 7.4	7.5 - 8.4	8.5 - 9.4	9.5 - +∞
C11	thousand	0 - 289	290 - 319	320 - 349	350 - +∞
C12	thousand	0 - 5050	5051 - 6520	6521 - 7999	8000 - +∞
C21	%	0 - 25	26 - 50	51 - 75	76 - 100
C22	%	0 - 25	26 - 50	51 - 75	76 - 100
C23	%	0 - 25	26 - 50	51 - 75	76 - 100
D11	thousand	0 - 47	48 - 54	55 - 59	60 - +∞
D12	number	0 - 42	43 - 49	50 - 59	60 - +∞
D13	number	0 - 70	71 - 80	81 - 90	91 - +∞
D14	%	0 - 50	51 - 70	71 - 90	91 - 100
D15	%	0 - 50	51 - 70	71 - 90	91 - 100
D21	number	0 - 30	31 - 50	51 - 70	71 - +∞
D22	%	0 - 30	31 - 50	51 - 70	71 - 100
D31	number	0 - 20	21 - 40	41 - 60	61 - +∞
D32	number	0 - 40	41 - 80	81120	121 - +∞
D41	number	0 - 8567	8568 - 44999	45000 - 79999	80000 - +∞
D42	number	0 - 3809	3810 - 3999	4000 - 4499	4500 - +∞
D51	number	0 - 370	371 - 499	500 - 699	700 - +∞
D52	thousand	0 - 150	151 - 180	181 - 210	211 - +∞
D61	number	0 - 30	31 - 65	66 - 99	100 - +∞
D62	个 trillion	0 - 1.0	1.1 - 1.4	1.5 - 1.9	2.0 - +∞

FIGURE 3 | National fitness assessment index interval reference standard table.

CONCLUSION

At present, China is in the key stage of transforming into a "sports power," with both opportunities and challenges. How to grasp this key journey, build a higher level and higher quality national fitness, and form a national fitness work pattern of "government led, social coordination, public participation, and legal guarantee" is an important topic. Based on a deep understanding of the important connotation of "national fitness under social change," this article uses the improved "balanced scorecard" method to construct an evaluation index system of national fitness development, including 4 primary indicators, 14 secondary indicators, and 49 tertiary indicators. Through the combination of qualitative analysis and quantitative analysis, the interval reference standard of the national fitness evaluation system is evaluated, and finally, the national fitness development index evaluation system is formed, to provide evaluation tools and theoretical reference for the development and improvement direction of national fitness.

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/s.

AUTHOR CONTRIBUTIONS

ZL and LL: conceptualization and methodology. ZL and YZ: resources. ZL and BH: supervision. ZL, BH, and SZ: writing—original draft. SZ: validation, software, and formal analysis. LL, YZ, RL, BH, and SZ: investigation. RL: visualization. ZZ and BH: data curation. YZ, RL, SZ, and ZZ: writing—review and editing. All authors contributed to the article and approved the submitted version.

FUNDING

This study was supported by the National Natural Science Foundation of China (Grant No. 71901141), the Soft Science Research Project of Shanghai Science and Technology Committee (Grant No. 22692104000), Municipal Key Curriculum Construction Project of University in Shanghai (Grant No. S202003002), and Shanghai Philosophy and Social Science Planning Project (Grant No. 2020BGL007).

ACKNOWLEDGMENTS

The authors would like to thank all participants who participated in the study.

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frontiers | Frontiers in Public Health

ORIGINAL RESEARCH
published: 27 May 2022
doi: 10.3389/fpubh.2022.857039

Construction of a Traceability System for Food Industry Chain Safety Information Based on Internet of Things Technology

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The continuous development of the social economy, has stimulataed an increase in the satndard of living and increased the deman for consumption resulting in the demand for high-quality and safe food has continued to increase. The so-called food safety means that the food that people eat under certain conditions will not harm human health. Frequent food safety incidents have highlighted the seriousness of my country's food safety problems and exposed loopholes in my country's food safety supervision. This article aims to study the construction of the Internet of Things technology in the food industry chain safety information traceability system, research on the RFID technology, GPS technology, and sensor technology in the Internet of things technology, and also conduct some research on the modules of the food industry chain safety information traceability system. This paper proposes to integrate the Internet of Things technology into the construction of the food industry chain safety information traceability system. First, a detailed analysis of some of the technologies that may be used is carried out, and then through the investigation of people on food safety and other aspects, and the food traceability system satisfaction survey. The experimental results in this article show that 40% of women pay more attention to food safety. Of course, in the satisfaction survey of the food safety traceability system based on the Internet of Things technology, it has been recognized by more than 20% of the people.

Keywords: Internet of Things technology, food industry chain, traceability system, industry chain, safety system

OPEN ACCESS

Edited by:
Fu-Sheng Tsai,
Cheng Shiu University, Taiwan

Reviewed by:
Wayne Martindale,
University of Lincoln, United Kingdom
Yun Zhang,
Dalian Neusoft University of Information, China

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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *18 January 2022*
Accepted: *06 May 2022*
Published: *27 May 2022*

Citation:
Lin S, Shi Q and Zhou N (2022) Construction of a Traceability System for Food Industry Chain Safety Information Based on Internet of Things Technology. Front. Public Health 10:857039. doi: 10.3389/fpubh.2022.857039

INTRODUCTION

In recent years, worldwide food safety accidents have occurred frequently, leading to a wide range of serious consequences. Continued food safety incidents not only seriously threaten the health of consumers, but also affect the healthy, sustained and stable development of the food industry. Food safety issues have attracted more and more attention from consumers who are more and more aware of food safety, and the supervision of news organizations and public opinion has also played a certain role. On the other hand, there are still considerable loopholes in our food safety supervision system. Fake eggs have been a threat for more than ten years without supervision. The society needs the establishment of a higher-level food safety system. Food safety issues are not as simple as government supervision, but have risen to social, economic and people's livelihood issues.

How food safety issues are handled is a manifestation of the government's concept of governance and other aspects, which in essence severely tests all levels of government. Therefore, in recent years, people have been keen to discuss how to effectively supervise food safety. The current problem that needs to be solved is how to effectively pre-warn food safety issues in the safety supervision of food circulation, and how to deal with emergencies in a timely and proper manner, so that normalized supervision can reach the level of efficiency, and the most timely and effective way to get these problems. The solution is to establish a food safety traceability system. The food quality chain involves multiple links, mainly including the quality control of raw materials and the transportation of raw materials at the place of production of raw materials, the control of product production processes by food processing plants, the control of product quality, and the storage of products by sales intermediaries, until use by end customers. If people want to eat healthy food, they must supervise all aspects of the food and control every aspect in order to ensure the quality and safety of the products.

The creation of a safety information traceability system for the food industry chain not only makes an important contribution to enhancing the overall image of the industry, building a good corporate brand, and enhancing the core competitiveness of the company. At the same time, the establishment of a food safety traceability system has increased the depth of supervision of the government's law enforcement and supervision departments, improved supervision efficiency, and established a set of standards and systems for a food safety traceability platform. From a technical perspective, the Internet of Things technology is used to solidify methodologies such as HE in the software and hardware products, and promoted and applied in the traditional food planting, breeding, processing, logistics, and circulation industries. Technological innovation in traditional industries plays a powerful role in promoting the mature and reliable use of RFID, GPS and other technologies. In the development of the food industry, the establishment of a public food safety traceability information query and service platform provides an expandable basic platform for the promotion of other traceability systems in the fast-moving consumer goods field. It has played a significant role in promoting the construction of traceability information service systems in other agricultural and sideline products, poultry, fruit and other industries. At the same time, the establishment of an information security traceability system for the food industry chain based on the Internet of Things technology ensures that consumers have the right to know all aspects of food production. The food safety traceability system establishes a standard identification system that meets international standards in all aspects of food logistics, and ensures that all aspects of the supply chain are properly identified, improving the reliability of product sources and the speed of information transmission and processing, and integrating electronic data Exchange, e-commerce and world trade are combined.

Internet of things technology is widely used. In an article, Zhao-Hui elaborated on the digital construction of museums and proposed the idea of using the Internet of Things technology to build digital museums. Intelligent navigation based on RFID technology provides a new way for the construction of intelligent museums (1). In coal mining, Dong et al. (2) conducted a research experiment on the safety and maintenance of coal mine plant systems as an example, which changed the current model of coal mine plant management and ensured the safe and highly reliable operation of coal mine plant. GPS, as a part of the perception level of the Internet of Things technology, is also being used more and more widely. Braun et al. presented a direct comparison of non-isotropic, integrated water vapor measurement between a ground-based global positioning system (GPS) receiver and a water vapor radiometer (WVR). Use the multi-path map of a specific site to perform station-related error correction on GPS observations (3). With the continuous development of social science and technology, food safety has attracted more and more attention. Scott pointed out in the study that the incidence of foodborne diseases is increasing globally. Although the food-borne disease data collection system often misses a large number of sporadic infections in the home, it is now generally accepted that many food-borne diseases are caused by consumers improperly handling and preparing food in their own kitchens (4). In the research on food safety issues, He et al. proposed various ARGs and antibiotics that are ubiquitous in pig manure and wastewater. Most ARGs and antibiotics survive in the farm waste treatment system for food safety and human health (5). Similarly, the Hsu et al. (6) study found that subjective understanding of organic food, health awareness and food safety concerns are important factors that affect the willingness to buy organic food. As food safety has attracted more and more attention, the food industry chain safety information traceability system has gradually entered the public's field of vision, and is gradually affecting people's lives. Hong established a research model in a study to analyze the impact of supply chain quality management and traceability systems on the quality performance and financial performance of companies in the food, pharmaceutical and automotive industries. And use the traceability system as a parameter to investigate the impact of the appropriate actions of the enterprise on the consumer's product quality complaints on the performance of the enterprise (7). Although the development of the Internet of Things technology and the information security traceability system of the food industry chain has promoted the improvement of food safety. However, these technologies and systems are still subject to restrictions and power, network restrictions in use, and the actual use costs are also relatively large.

The innovation of this article lies in the integration of modern Internet of Things technology into the traceability system of food safety. Through the use of related technologies of the Internet of Things, such as video surveillance technology to supervise the brotherhood of food production, people can connect through video. Line check the production situation of various environments such as food raw material production, food processing, and food transportation (8). For another example, GPS technology can be used to locate the food from where it was transported, where it has been, when it arrived, etc. to conduct a supervision to ensure that the food is standardized and reasonable throughout the transportation process, so as to ensure that food safety is not affected during the transportation

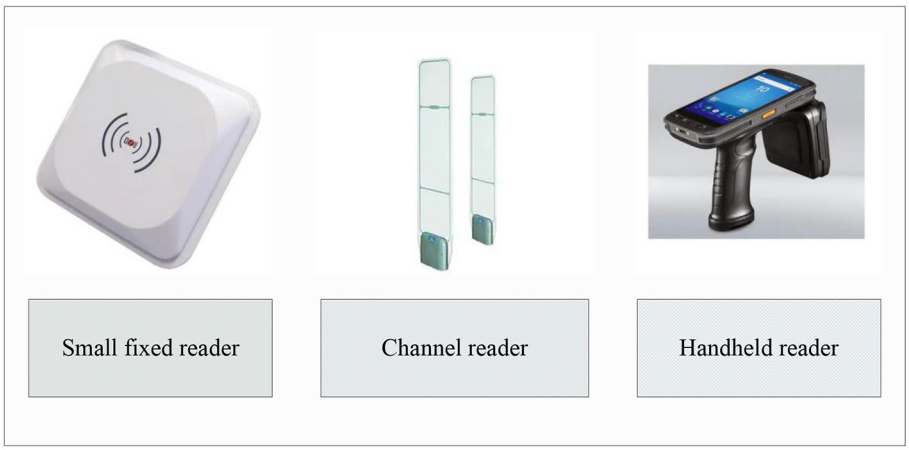


FIGURE 1 | Commonly used readers.

process (9). By applying the Internet of Things technology to the food safety traceability system, it is not only an emphasis on food safety, but also a concern for the people's livelihood by the governing and law enforcement agencies. Improving people's food safety and protecting people's physical and mental health through modern scientific and technological means is the goal of scientific and technological development, and it is also what people are constantly looking forward to.

APPLICATION METHOD OF INTERNET OF THINGS TECHNOLOGY IN FOOD SAFETY INDUSTRY CHAIN SAFETY INFORMATION TRACEABILITY SYSTEM

Internet of Things Technology

Simply put, IoT technology is the connectivity of all objects to the Internet through radio spectrum recognition and other message detection devices for intelligent identification and administration (10). In other words, IoT is the new technology that connects various sensors to the available network. The Internet of Things is another technological revolution in the information industry, representing the future development trend of computers and communications, and affecting the future social and economic development (11). The Internet of Things is the fusion of some technologies active in various fields, and these technologies have already had some applications (12, 13). In the food industry chain information security traceability system, a large number of Internet of Things technologies must be used. This article studies and describes the more important technologies.

Rfid Technology

Radio spectrum recognition uses radio wave high speed message exchange and storage technology, combined with wireless communication and data acquisition technical, connected to the database system, to achieve non-contact two-way communication, so as to achieve the identification purpose of data exchange. And the complex system is connected in series (14).

Radio frequency identification technology uses the three components of tags, readers and computer systems to identify item information while transmitting information (15). Among them, the RFID tag is mainly used to store the product information of the identified object and has unique identification; the reader can read and write the information of the RFID tag. The readers generally used are handheld and fixed. The fixed type can be divided into two types: channel type and small fixed type, as shown in **Figure 1**.

The fundamental working theory of RFID is not complex. Its main elements are that the tag enters the magnetic field and sends a code to the reader, the antenna accepts the RF signal sent by the reader and uses the power gained by the sensing electrical field to send the message of the manufactured goods stored in the chip, or to activate a signal of a particular spectrum of frequencies. After the device reads and decodes the read information, the processed relevant data will be sent to the a central message system (16). **Figure 2** shows the working principle of RFID technology.

According to various power modes of electronic tags, RFID can be divided into two categories: passive RFID and active RFID. There is no battery on the passive RFID electronic tag, and all the power required for work can be obtained by converting the electromagnetic wave sent from the received reader (17). The active RFID electronic tag is equipped with a battery that can use built-in power. Since the active area is formed around the tag, the remote radio frequency can also be identified by the reader. In the RFID system, the concept of the frequency band refers to the frequency range in which the reader transmits, receives and reads the tag signal through the antenna (18). From the perspective of application, the working frequency of the radio frequency tag is also the working frequency of the radio frequency identification system, which is one of the most important functions. The operating frequency of the RFID system not only affects the performance and size of the tag, affects the distance of the

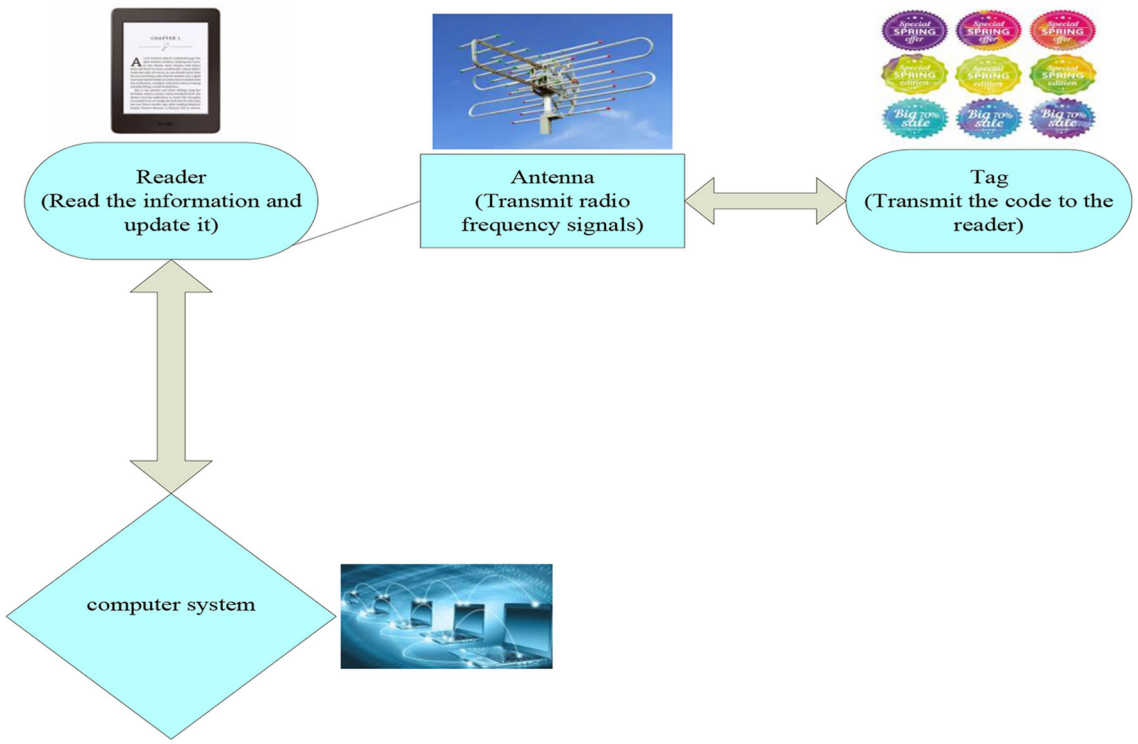


FIGURE 2 | RFID working principle diagram.

reader, but also affects the price of the tag and the reader, so the choice of frequency is very important (19). **Table 1** mainly shows the specifications and characteristics of frequency bands used internationally. RFID tags are mainly divided into three categories: active, passive and semi-passive.

From the above table, high-frequency RFID tags can more appropriately meet the needs of the food safety traceability system discussed in this article. If this frequency band tag is applied in fields such as bus cards, the stability is good and the price is relatively cheap. At the same time, high-frequency RFID tags have good storage properties, easy to read and write tags, and good security and reliability. In the end, high-frequency RFID was selected as the personal identification carrier in production.

Gps Technology

GPS is a type of movement sensitive technique, which is an important technique to extend the network of things to mobile objects to collect information of mobile objects, and also an important technique for logistics intelligence and high level road traffic system (20). It is a high-precision radio navigation positioning system based on artificial earth satellites. It can provide accurate geographic location, vehicle speed and precise time information anywhere in the world and in near-Earth space. As a particularly important part of the food industry chain-modern logistics, GPS vehicle navigation system is a particularly important technology. With the use of GPS positioning technology and vehicle dynamic scheduling technology, logistics vehicles not only improve on-time operation, but also make it possible to find the route and stay time of transport vehicles during the entire transportation. This is to ensure the principle of food. The transparency of the entire transportation process of raw materials, finished products, and packaging materials provides a great guarantee (21). The working process of the car GPS positioning system is shown in **Figure 3**.

Video Surveillance System

The video surveillance system is also called closed-circuit television surveillance system (CCTV), as an important means to supervise the standards, safety and orderly work of the food production industry chain, and it also provides an important guarantee for the safety of food transportation (22). Monitoring is the physical basis for real-time monitoring of key departments or important places in various industries. Management departments can obtain effective data, images or sound information through it, and monitor and memorize the process of sudden abnormal events in time to provide efficient, Timely command and height, deploy police force, handle cases, etc. As an important part of various professional systems in food production, the video surveillance system is a professional communication method with certain security capabilities. It can pass through the front-end camera and its auxiliary equipment (codec, disk array, switch, display, etc.), and view the real-time monitoring images on site through a certain transmission method. At the

TABLE 1 | RFID main frequency band standards and characteristics.

	Low frequency	High frequency		UHF	Microwave
Working frequency	125–134 KHz	13.56 MHz	JM13.56 MHz	868–915 MHz	2.45–5.8 GHz
Market share	74%	17%	2003	6%	3%
Reading distance	1.2 m	1.2 m	1.2 m	4 m	4 m
Speed	Slow	Medium	Soon	Quick	Soon
Humid environment	No effect	No effect	No effect	Greater impact	Greater impact
Directionality	Without	Without	Without	Part	Have
Applicable frequency	Yes	Yes	Yes	Part	Part
Existing ISO standards	11,784/85, 14,223	18,000- 3.1/14,443	18000-3.2/ 15,693,A,B,andC	EPC C0, C1,C2,G2	18000-4-
Scope of application	Natural gas	Library	Air transport	Trailer	Toll

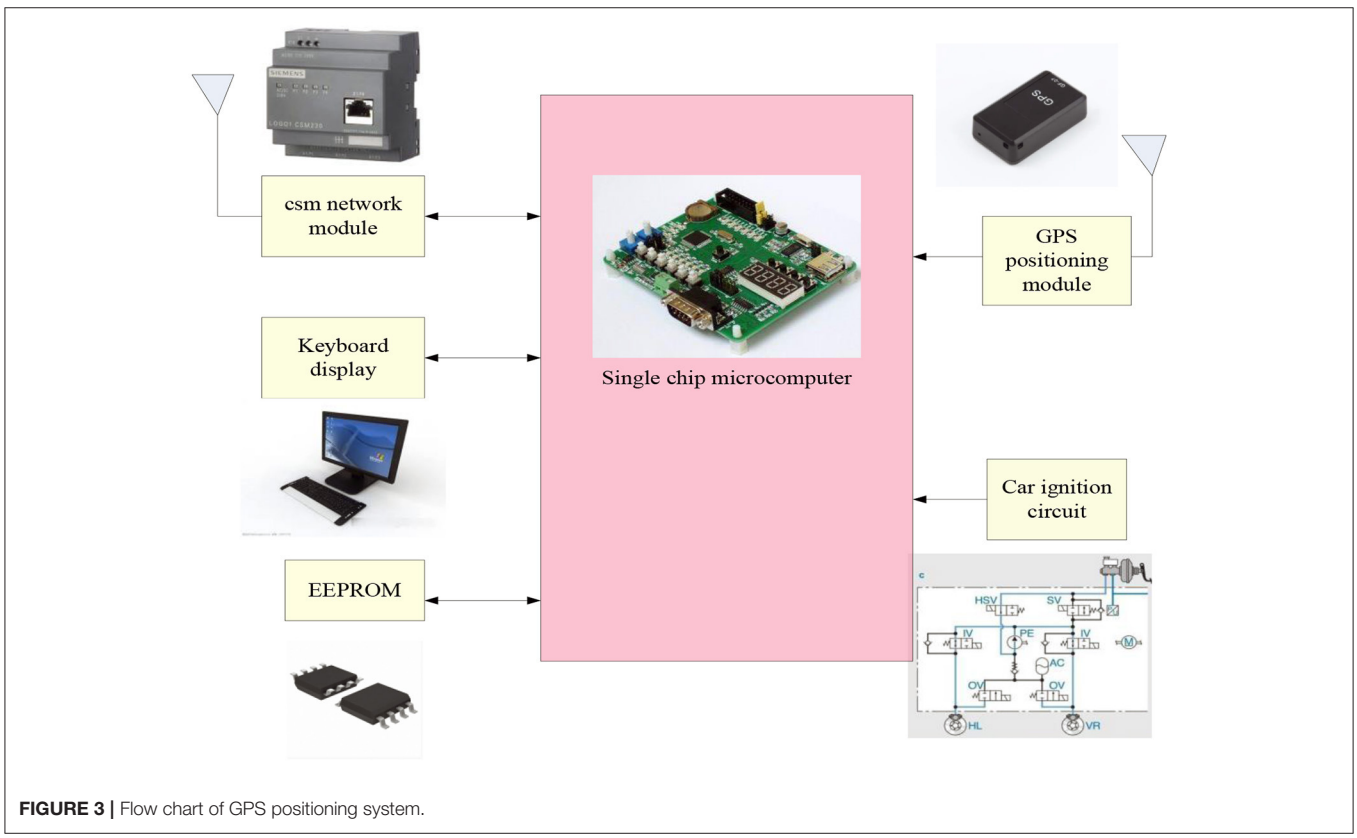


FIGURE 3 | Flow chart of GPS positioning system.

same time, the video monitoring system can perform alarm linkage with fire protection, AFC and other systems, making the functions of the video monitoring system more complete and powerful. The video surveillance system transmits video signals in the transmission channel through transmission media such as optical fiber, coaxial cable, and network shielded cable. It adopts digital surveillance technology, video image compression technology, and digital network technology to form an independent and complete TV from the image display from the camera. The system, combined with the functions of multi-screen display, monitoring, compressed storage, retrieval and playback, and recording of digital video images, reflects the monitored objects in real time, vividly and truthfully, and records them through video monitoring storage devices, which can be widely used in various field of surveillance and security system (23).

The front-end equipment of the video surveillance system is usually composed of the camera body, lens (long focus/short focus), mounting bracket, protective cover, optical transceiver, optical cable splice box and other components. Each component is transmitted through a variety of transmission methods, such as coaxial cable, wireless AP or optical fiber transmission medium establishes a closed loop with the central switching equipment and server (24). In the actual video surveillance system, the front-end equipment will be selected according to the actual environment and conditions, but the camera and lens are the most basic components. Only the front-end has the video image collection, and

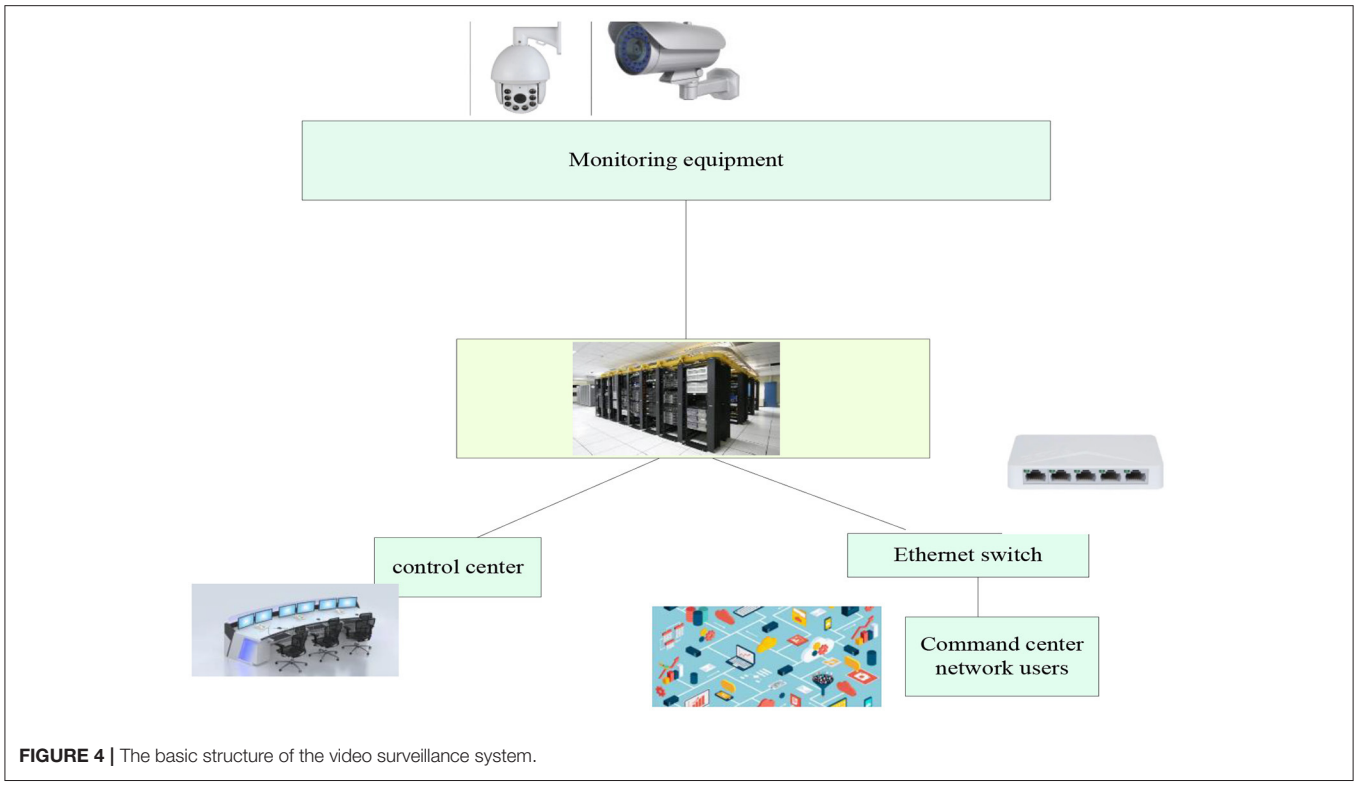


FIGURE 4 | The basic structure of the video surveillance system.

the back-end video image storage and monitoring can be carried out. **Figure 4** shows the basic structure of the video surveillance system.

Image Sensor Technology

Sensors are a general term for devices that can sense prescribed measurement values and convert them into usable output signals according to specific rules (25). Some developed countries put sensor technology and communication technology in the same position. With the development of modern science, sensor technology is regarded as one of the three pillars of information technology. New fields closely related to modern science are also developing rapidly, among which are widely used. While promoting the development of various fields in the fields of industrial automation detection technology, aerospace technology, military engineering, medical diagnosis, etc.

Image Processing Related Technologies

Digital Image Processing

Digital image processing technology is a multi-disciplinary field. It uses computer to remove noise, enhance, restore, segment, extract features and other processing methods and technologies for images. Although its development history is not long, it has attracted extensive attention in various fields (26).

The three colors of R, g, and b are the three primary colors of nature. The light with various color characteristics that people can usually see can be formed by mixing these three colors; on the contrary, the color characteristics of any kind of light can also be formed by r, g, b these three colors indicate. In the color space of the RGB model, three colors of r, g, and b can be used to establish a coordinate axis, and the values of these three colors are all assigned to 1, as shown in **Figure 5**.

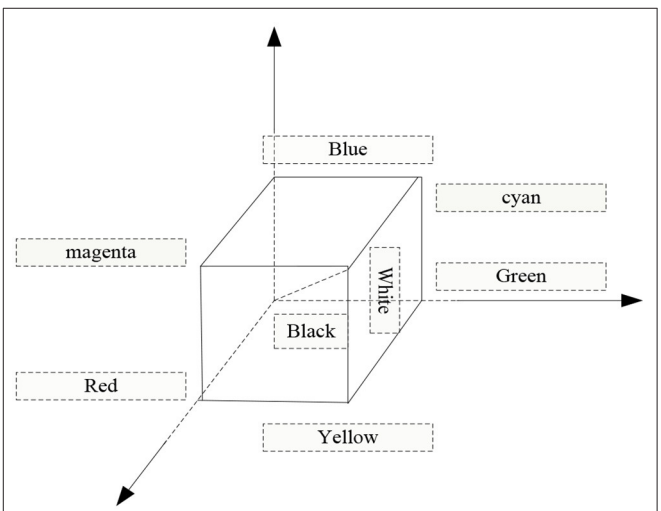


FIGURE 5 | RGB color space.

This model is very common in our daily life, and most of the color images we usually see are based on this model. To make the color model more robust to illumination, the chrominance information and brightness information of the

color must be separated from each other (27). As a result, people have developed several color models that separate chroma and brightness from each other. Such as YUV color model and HSV color model. YUV, is a color coding method. Often used in various video processing components. YUV allows for reduced bandwidth for chroma taking into account human perception when encoding photos or videos. In these models, Y is also the brightness of the color, while U represents the difference between red and green in the chromaticity of the color; V represents the difference between red and blue in the chromaticity of the color. The conversion relationship between YUV color model and HSV color model is as follows:

$$Y = 0.299^{*}r + 0.587^{*}g + 0.144^{*}b \quad (1)$$

$$U = -0.148^{*}r - 0.289^{*}g + 0.437^{*}b \quad (2)$$

$$V = 0.615^{*}r - 0.515^{*}g - 0.1^{*}b \quad (3)$$

This model is obtained by separating the brightness and chrominance information of the color in the RGB model. The purpose of this is to compress the frequency band so as to have sufficient bandwidth (28).

The color space is somewhat different from the aforementioned YIQ and YUV color models. The color model uses the CCIR 601 coding scheme, y represents the brightness information of the color, cb represents the cyan information of the chromaticity, and cr represents the red information of the chromaticity. Because Cb and cr are independent of each other, they have the characteristics of two-dimensional plane clustering. This color model can also be converted from the RGB color model. The specific conversion formula is as follows:

$$\begin{bmatrix} y \\ cb \\ cr \end{bmatrix} = \begin{bmatrix} 0 \\ 128 \\ 128 \end{bmatrix} + \begin{bmatrix} 0.29900 & 0.58700 & 0.11400 \\ -0.16874 & -0.33126 & 0.50000 \\ 0.500000 & -0.41869 & 0.08131 \end{bmatrix} \begin{bmatrix} r \\ g \\ b \end{bmatrix} \quad (4)$$

The chromatic model also takes into account the fact that the human eye is not sufficiently sensitive to chromatic changes in color, but is more responsive to the luminance of colors.

HSV, which can also be called HSI, is a color model proposed by Munseu based on the separation of chroma, saturation, and brightness. HSV is an intuitive color model for the user. In this color model, H represents the chromaticity of the color information, that is, the chromaticity information of the color is represented by this one channel, unlike the previous color model, which is represented by multiple channels. S represents the saturation of the color information, that is, the depth of the color. V represents the brightness of the color information. The color model established in this way can be represented by a hexagonal pyramid, as shown in **Figure 6**.

The expression of the HSV color model can also be obtained through the conversion of the RGB color model. The obtained process is to first normalize the RGB color model, and then convert it to an HSV model. The conversion process is as follows:

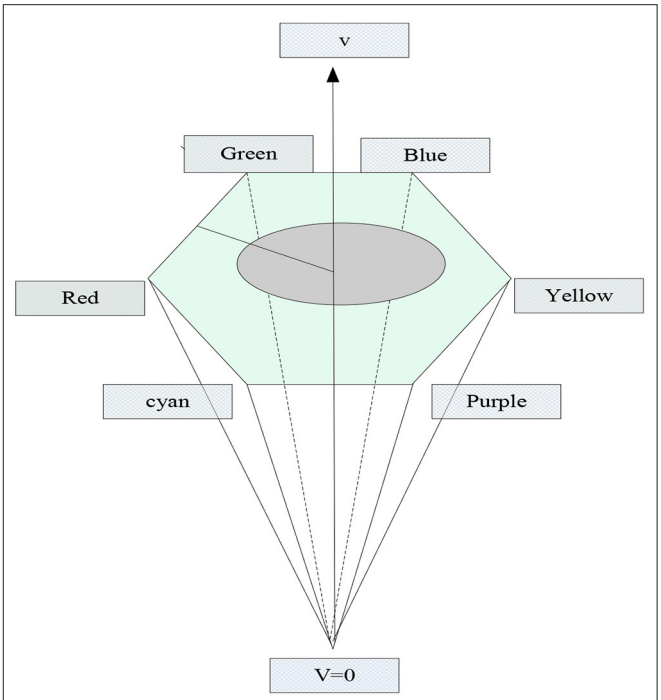


FIGURE 6 | HSV color model.

Normalization of RGB color model:

$$H' = \begin{cases} \frac{e-t}{Max(q,e,t)-Min(q,e,t)} & q = Max(q,e,t) \\ \frac{t-q}{Max(q,e,t)-Min(q,e,t)} + 2 & e = Max(q,e,t) \\ \frac{q-t}{Max(q,e,t)-Min(q,e,t)} + 4 & t = Max(q,e,t) \end{cases} \quad (5)$$

Convert to HSV model:

$$H = \begin{cases} H'^{*}60 & H' \geq 0 \\ H'^{*}60 + 360 & H' < 0 \\ undefined & S = 0 \end{cases} \quad (6)$$

$$S = \begin{cases} 0 & V = 0 \\ 1 - Min(q,e,t) & V \neq 0 \end{cases} \quad (7)$$

$$V = Max(q,e,t) \quad (8)$$

Maximum Between-Class Variance Method

This algorithm was researched and proposed by Japanese scholar Otsu Nobuyuki in 1979, it is an automatic threshold value method suitable for bimodal situations, also known as the Otsu method. This is an image segmentation method for segmenting grayscale images. It is named after its own name and is called the OTSU algorithm. Based on the characteristics of this algorithm, it can be named as the maximum inter-class covariance approach. Since this method performs segmentation of individuals according to the features of grayscale histogram, it is often classified as histogram segmentation in association with

an issue of identity in image method. The idea of this method is to classify the image into two classes, one for the target class and the other for the background class. The task of the algorithm is to find the best segmentation threshold, which can make the image target class and background class the best separation. The steps for image segmentation using this algorithm are as follows:

If the total number of pixels of the entire image is set to W, then images with pixel gray levels of n share Wn, and the images always contain M gray levels, and we can get:

$$W = \sum_{n=0}^{M-1} W_n (n = 0, 1, 2, ..., M-1) \tag{9}$$

Let the probability that a pixel whose grayscale is n is in the image is En. For En, there are:

$$E_n = W_n / W, E_n \geq 0, \sum_{n=0}^{M-1} E_n = 1 \tag{10}$$

Assuming that the segmentation threshold between the image target class and the background class is a, the target class is denoted as F1, and the background class is denoted as F2, we can get: (1) F1 contains all gray levels in (0, 1, 2,. .., pixels between a); (2) F2 contains all pixels with gray levels between (a+1, a+2,..., n+1). Let Y be the probability of F1 and P be the probability of F2, then:

$$Y = \sum_{i=0}^{n} M_n \tag{11}$$

$$P = \sum_{i=i+1}^{n} M_n \tag{12}$$

Let A be the mean value of F1 and B be the mean value of F2, then:

$$A = \sum_{i=0}^{n} iM_i / Y \tag{13}$$

$$B = \sum_{i=i+1}^{n-1} iM_n / P \tag{14}$$

Let α1 be the variance of F1 and α2 be the variance of F2, then:

$$\alpha 1 = \sum_{i=0}^{n} (i - \mu_0)^2 M_n / Y \tag{15}$$

$$\alpha 2 = \sum_{i=i+1}^{n-1} (i - \mu_i)^2 M_n / P \tag{16}$$

Therefore, it is assumed that α1 is the intrastate covariance of objective and background classes F1 and F2, α2 is the intersubclass covariance of objective and background classes F1 and F2, and μ0 is the average gray level of the image. The following expressions can be obtained:

$$\alpha 1 = Y\alpha 1 + P\alpha 1 = \sum_{i=1}^{i} (i - \mu_0)^2 M_n + \sum_{i=i+1}^{a-1} (i - \mu_1)^2 M_n \tag{17}$$

$$\alpha 2 = Y(\mu_0 - \mu_1)^2 + P(\mu_1 - \mu_r)^2 = YP(\mu_1 - \mu_0)^2 \tag{18}$$

The maximum between-class variance method is more suitable for single-threshold segmentation. Artificial road signs with different colors are used in the article. When extracting, the artificial road signs need to be extracted one by one, which requires the extraction and distribution operation of each artificial road sign. For the extraction of artificial road signs of each color, it is a case of a single threshold segmentation, so the maximum between-class variance method is also more suitable for the image segmentation of this article.

Food Safety Traceability System Structure

The so-called food safety traceability system is a targeted industry solution in the food safety system. My country has initially established some food traceability information systems and exchange platforms. These food safety traceability systems use RFID electronic tags, two-dimensional barcodes, wireless sensing and network transmission, video monitoring technology, etc., to automatically record the entire food supply chain information. And store the information in the corresponding data control system to realize data query and backtracking. Mainly refers to tracking the operation path of food raw materials according to the process of the supply chain, and the direction is from the producer to the consumer; while traceability refers to the reverse identification of the target food unit from the downstream consumer of the supply chain to the upstream producer, and through the record The scanning method traces back the supply process of a certain food monomer. Since the information of food production, processing, packaging, storage, transportation, sales and other links are recorded in the back-end database, consumers and supervisory departments can learn information about any link in the supply chain through electronic tags anytime and anywhere. As soon as a security incident occurs, determine the link where the problem occurred, define the responsible party, and take recall measures in a timely manner to minimize the loss of consumers and enterprises.

The traceability system is generally divided into five links, namely, production, packaging and processing, warehousing and transportation, sales, and supervision. This article mainly analyzes the supervision link.

Based on the hypothesis of "economic man," one of the main pursuits of commercial enterprises is to maximize profits. As long as it is profitable, the enterprise will choose to take risks or even commit crimes. Therefore, the behavior of enterprises needs the supervision of government regulatory agencies. However, in real life because of this or because of that reason, the supervision work of the government supervision department is not so smooth, and food safety issues are still emerging. The following is an analysis of the game situation between the enterprise and the government

TABLE 2 | User profile table.

String name	Type of data	Field size	Primary key	Can it be empty
ID	char	20	Yes	No
Name	varchar	32	No	No
Password	char	32	No	No
Sex	int	8	No	No
Paypasword	char	32	No	No
Phone	char	11	No	No
Address	varchar	20	No	No
Email	carchar	20	No	No
Accountid	int	8	No	No

TABLE 3 | Product profile table.

String name	Type of data	Field size	Primary key	Can it be empty
ID	char	20	Yes	No
Number	char	20	No	No
Name	varchar	32	No	No
Num	int	8	No	No
Price	float	11	No	No
Time	varchar		No	No
Type	int	8	No	No
Description	varchar	200	No	No
Path	varchar	20	No	No
Status	int	8	No	No
Sellerid	char	20	No	No
Codeid	char	42	No	No
Productid	int	11	No	No

TABLE 4 | Two-dimensional code coding table.

Field name	Type of data	Field size	Primary key	Can it be empty
ID	char	42	Yes	No
Status	int	11	No	No
Code	char	32	No	No

TABLE 5 | Verification record table.

Field name	Type of data	Field size	Primary key	Can it be empty
ID	char	42	Yes	No
Time	int	11	No	No
Lon	float	17	No	No
Lat	float	17	No	No
Typeld	int	11	No	No
Num	int	11	No	No
Lastscantime	int	11	No	No

supervision department from the perspective of game theory, and provides solutions for such problems.

The government supervision department has two choices of supervision and non-supervision for the production behavior of the enterprise. The enterprise also has two choices of producing qualified products and producing unqualified products. From the perspective of the government supervision department, it is assumed that the government supervision department adopts supervision. The expected benefits from non-regulatory measures are A1 and A2, respectively. According to some data, we can get:

$$A1 = a(w - t) + (1 - a)(w - t) \tag{19}$$

$$A2 = aw + (1 - a)^{*}0 \tag{20}$$

According to the solution method of the game Nash equilibrium strategy, let A1 = A2 to obtain

$$a = (w - t/w) = 1 - t/w \tag{21}$$

According to the above formula, the probability n of an enterprise producing qualified products is related to the cost T and utility w obtained by the government supervision department in the supervision process. The smaller t or W is, the greater the probability a of an enterprise producing qualified products. Therefore, in order to ensure that an enterprise produces qualified products, the government supervision department should improve the supervision efficiency on the one hand. That is to reduce the supervision cost T. On the other hand, the higher authorities should affirm the work of the regulatory authorities and give appropriate awards, that is, increase effectiveness a.

FOOD TRACEABILITY SYSTEM FUNCTION ANALYSIS AND DATABASE DESIGN EXPERIMENT

System Function Analysis

This topic is a food-based item traceability system, where the items are mainly agricultural products. My country's food safety supervision can be roughly divided into three stages: market access verification, production and sales supervision, and accident handling. The items are monitored from the soil, and the daily temperature and humidity, soil environment, etc. can be intuitively monitored. An environment with potential growth hazards raises alarms. After the goods are mature, they are marked with a unique QR code and sold on the e-commerce platform under the system. After purchasing this item, the user can scan it to query the entire growth, production, packaging, sales, circulation, production location, authenticity, etc. of the item.

The ultimate goal of food safety supervision is to ensure consumer safety, so that consumers can buy with peace of mind and eat with confidence. Therefore, we will establish an item traceability system for enterprise platform administrators to trace items. This system can also sell items online, providing consumers with purchases and also facilitating the follow-up tracking of items by enterprises. Therefore,

this item traceability management system probably has the functions of item production source data supervision, corresponding item security QR code generation, item sales, logistics tracking, anti-counterfeiting traceability and other functions.

Database Design

This system uses mysql database for development. Since mysql's innodb engine supports transactions, it can complete order payment and other functions. The structure of each table in the system database is as follows.

User Profile Table

It is used to record the basic messages such as user name, cell phone number and login password of registered users. The specific structure is shown in **Table 2**.

Product Information Table

This table mainly records related information such as product number, name, inventory, price, shelf time, and corresponding QR code. The primary key of this table is the product ID, and the specific structure is shown in **Table 3**.

Two-Dimensional Code Coding Table

This table mainly records the number of the two-dimensional code and its usage status. 0 means not activated, 1 means activated, and 2 means destroyed. The specific structure is shown in **Table 4**.

Verification Record Table

This table mainly records the corresponding QR code number, scanning time, scanning location, scanner's mobile phone model, scanning times, last scanning time, etc. The specific structure is shown in **Table 5**.

ANALYSIS OF RELATED RESEARCH AND EXPERIMENT RESULTS OF FOOD TRACEABILITY SYSTEM

Experimental Sample Analysis

A total of 1,691 people participated in this experiment, including 580 men and 1,111 women. It can be concluded from the gender that women are significantly more concerned about food safety than men. From the analysis of age distribution, the proportion of middle-aged people participating in the survey is relatively high, followed by adolescents' attention to food safety, young consumers have a high tolerance for quality and safety, and children and elderly people's attention to food safety is relatively low. However, this survey needs to state that there are many elderly people who are willing to participate in the survey. However, a considerable number of residents in this age group have certain shortcomings in writing, so some elderly people did not fill in this survey form.

Analysis of Survey Results

According to **Figure 7** and the previous survey results of this topic, the statistical results can be analyzed, and a comparison chart of male and female residents' concerns about food safety in various regions can be obtained, as shown in **Figure 7**.

From **Figure 7**, we can conclude that regardless of the number of people in that region, the number of women concerned about food safety is often higher than 40% of that of men. According to the survey data in the figure, the economies of South China and North China are more economical. People in developed areas also pay more attention to food safety.

In addition to conducting research and analysis on people of different genders, we also compiled a comparison chart of people of different ages on food safety concerns, as shown in **Figure 8**.

From **Figure 8** we can conclude that middle-aged people pay the most attention to food safety, followed by teenagers and young people. It can also be seen from the figure that in this survey process, more than 30% of the personnel came from the northern region, the Southwest is the least and may be affected by regional economic and cultural factors, which can show that in this field survey, the northerners paid the most attention to food safety.

In the statistics of this and other survey results tables, we also organized and summarized people with different educational backgrounds. **Figure 9** shows the specific statistics table we made.

From **Figure 9** we can know that people with middle or high education accounted for more than 35% of the total number of our survey, indicating that people with higher education are more concerned about food safety, but there are still most of them with junior high school education. There is also a high degree of concern for existing food safety.

We then obtained some data and made relevant statistics from the investigation of food safety production links and traceability system. The specific situation is shown in **Figure 10**.

From **Figure 10**, we can conclude that in the entire food production process, more than 36.5% of the people pay more attention to food processing and the production of food raw materials, and in the food safety system, people are satisfied with the food safety traceability system. The degree is 15.6% higher than the original food safety system.

CONCLUSIONS

The establishment of a food information safety traceability system based on the Internet of Things technology is a long-term and complex project, which is the basis for realizing food safety informatization. This paper studies the food information safety traceability system based on the Internet of Things technology. First, it conducts a detailed study on the Internet of Things

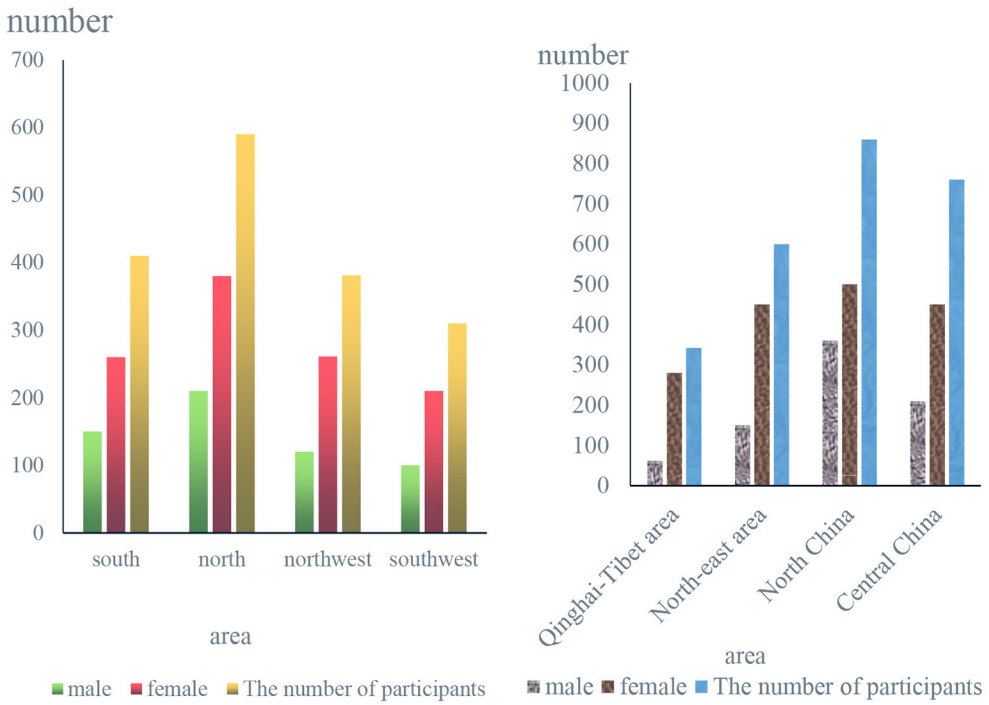


FIGURE 7 | Number of men and women concerned about food safety by region.

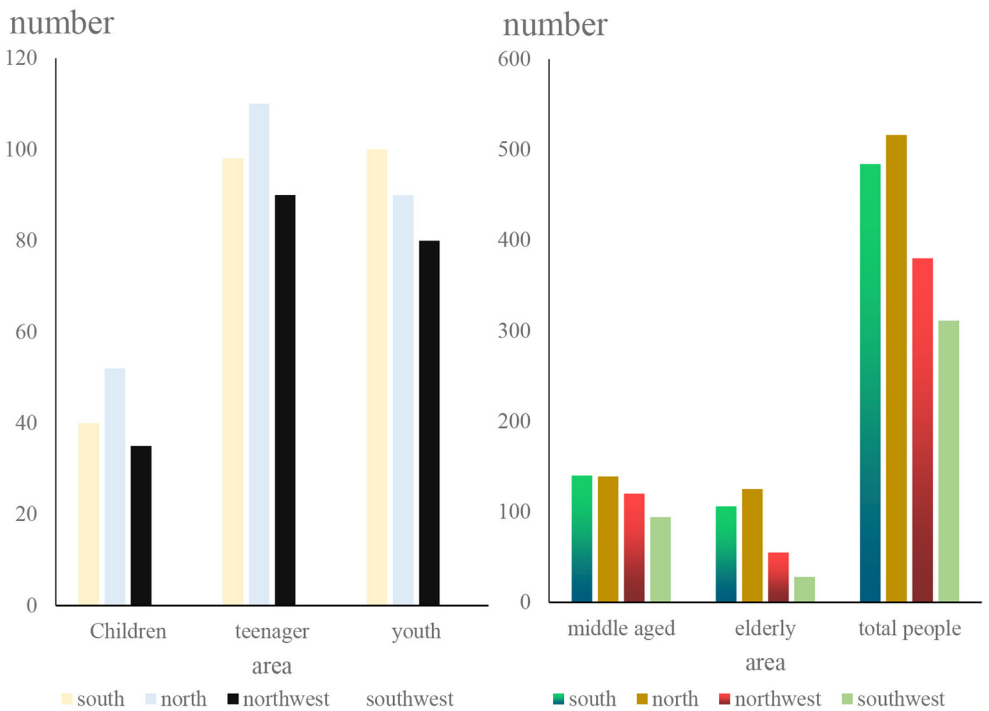


FIGURE 8 | Statistics of the level of attention paid to food safety by age groups.

technology and the food traceability system, and then conducts a survey on people's food safety related content. The survey results show that there are more than 40% of women are more concerned about food safety, and people are more concerned about food raw materials and processing. By using the Internet of Things technology to create a food safety information system,

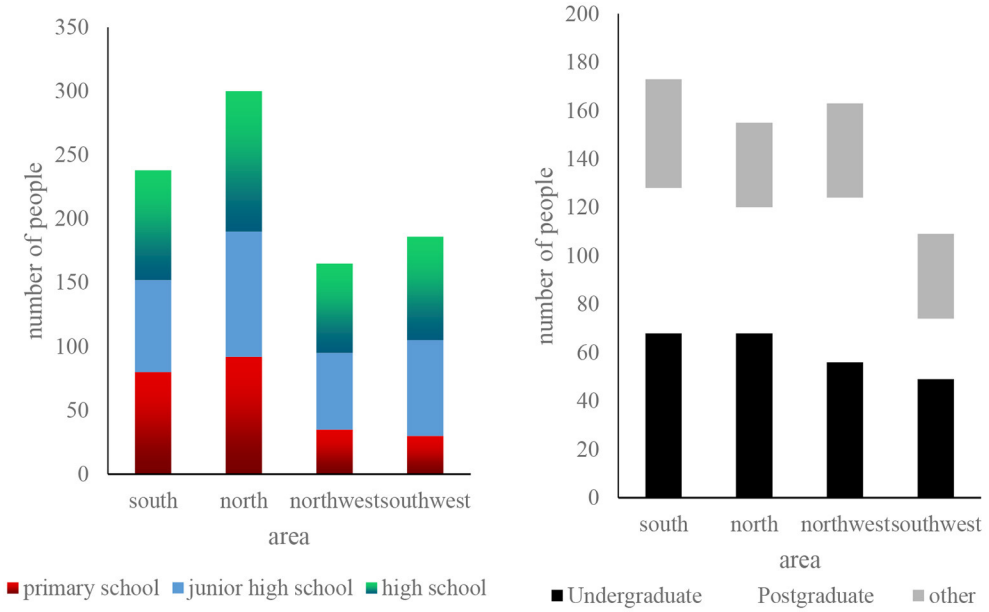


FIGURE 9 | Statistical table of the survey personnel's educational background distribution.

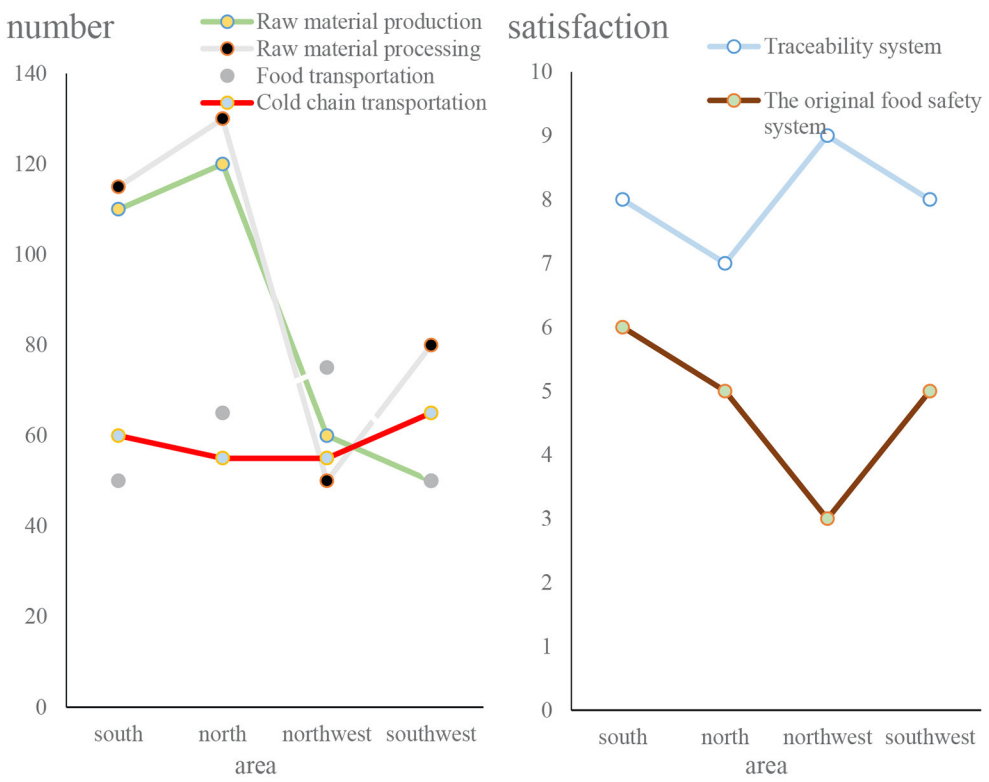


FIGURE 10 | Figure of the results of investigations on the food production process and traceability system.

not only can the production quality of the food produced in the production process be improved, and the entire food can be transparent in the production, processing, and transportation of raw materials, but also make people aware of the entire food system and the food industry chain. The security information traceability system is more satisfactory.

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

Ethical approval for this study and written informed consent from the participants of the study were not required in accordance with local legislation and national guidelines.

AUTHOR CONTRIBUTIONS

SL: write. QS: analysis. NZ: check. All authors contributed to the article and approved the submitted version.

FUNDING

This work was supported by Social Science Foundation Major Projects of China (18ZDA102) 2018 and Youth Project of Natural Science Foundation of China (72004089) 2020.

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frontiers | Frontiers in Public Health

ORIGINAL RESEARCH
published: 13 June 2022
doi: 10.3389/fpubh.2022.898148

Research Into Mental Health Prediction of Community Workers Involved in the Prevention of COVID-19 Epidemic Based on Cloud Model

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To get to know the mental status of community workers involved in the prevention of COVID-19 epidemic, provide them with mental counseling and guidance, and predict their mental health status, a cloud model for the mental health prediction of community workers involved in the prevention of COVID-19 epidemic was constructed in this paper. First, the method to collect data about mental health was determined; second, the basic definition of cloud was discussed, the digital features of cloud were analyzed, and then, the cloud theory model was constructed; third, a model to predict the mental health of community workers involved in the prevention of COVID-19 epidemic was constructed based on the cloud theory, and corresponding algorithm was designed. Finally, a community was chosen as the research object to analyze and predict its mental health status. The research results suggest that the model can effectively predict the mental health status of community workers involved in the prevention of COVID-19 epidemic.

Keywords: psychological well-being, prediction, community staffs who preventing and controlling epidemic, cloud model, algorithm

OPEN ACCESS

Edited by:
Fu-Sheng Tsai,
Cheng Shiu University, Taiwan

Reviewed by:
Hao Cheng,
Nanning Normal University, China
Aiping Kuang,
Guangxi Normal University, China

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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *17 March 2022*
Accepted: *05 May 2022*
Published: *13 June 2022*

Citation:
Huang J (2022) Research Into Mental Health Prediction of Community Workers Involved in the Prevention of COVID-19 Epidemic Based on Cloud Model. Front. Public Health 10:898148. doi: 10.3389/fpubh.2022.898148

INTRODUCTION

The COVID-19 epidemic first appeared in 2019 and quickly spread in China then. After experiencing local breakout and community-based transmission, it finally widely spread throughout China, and since April 2020, the epidemic has spread to more than 80 countries. A large number of studies suggest that acute stress disorder caused by public health emergencies such as the spread of acute infectious diseases can seriously affect people's confidence in life and work, thus doing great harm to the society. Specifically, after the outbreak of SARS in China in 2003, a large amount of patients suffered from stress disorder and mental disorder due to external trauma in many parts of China. Therefore, it is particularly urgent to alleviate such negative effects. In 2020, the World Health Organization declared the worldwide spread of COVID-pandemic, and to effectively prevent the disease, the Chinese government has adopted a lot of effective measures, including restricting the travel of people in key areas and mobilizing the whole society in the pandemic control. Also, under the leadership of governments at all levels, grassroots units have jointly formulated the epidemic prevention and control strategies. In addition, local communities, which are at the forefront of the epidemic control, have established a "four-in-one" epidemic prevention and control organ consisting of community cadres, property management

workers, community policemen, and medical workers at local healthcare centers to conduct in-depth investigation into the local epidemic prevention and control (1). In the face of the epidemic, in addition to taking scientific self-protection measures, it is also necessary for us to focus on our mental health and prevent ourselves from negative emotions such as anxiety, panic, and depression.

At present, the COVID-19 epidemic has not been eliminated as sporadic cases appear one after another everywhere, posing serious threat to people's health. Thus, it is necessary to conduct medical quarantine for close contacts and suspected infected persons to prevent the further spread of the epidemic. However, as China has a large population, it is suggested that they stay at home during their quarantine period (2). Also, the frequent occurrence of new cases poses a potential risk to workplace, and the implementation of closed-off management at high-risk communities will inevitably affect the mental health of local community workers. Furthermore, community workers often face new challenges and high work intensity during the epidemic prevention, and thus, they are easy to have emotional changes. Therefore, it is necessary to timely get to know community workers' work and emotions during the epidemic prevention and analyze relevant influencing factors, thus providing reference for conducting mental intervention for them (3).

An advanced method is adopted in this paper to effectively predict the mental health of community workers involved in the prevention of COVID-19 epidemic. Conventional fuzzy sets are used as theoretical basis to effectively deal with many engineering problems, such as engineering control optimization, data analysis, efficiency prediction, and fault diagnosis. To accurately predict the mental health of community workers involved in the prevention of COVID-19 epidemic, there is a need to obtain a large amount of relevant data and analyze and evaluate the hidden information with professional expertise and skills, so as to provide strong support for subsequent epidemic prevention and control. At present, the situation is complex, but to apply cloud model to predict the mental health of community workers involved in the prevention of COVID-19 epidemic can increase the data utilization rate and reduce the investment in labor. With the concerted efforts of researchers, the theoretical basis of cloud model is more sufficient, and the model can predict the mental health of community workers involved in the prevention of COVID-19 epidemic more effectively (4).

This paper mainly focuses on the application of cloud model in the prediction of mental health of community workers involved in the prevention of COVID-19 epidemic. According to the obtained data about mental health, the multiple rule reasoning process of cloud model was established, the technical routes and methods of prediction were analyzed, and the case analysis was conducted to verify the effectiveness of the method. Based on the existing data, extracting the useful knowledge behind a large amount of data can reduce the waste of data and provide technical support for improving the accuracy of predicting mental health of community workers involved in the prevention of COVID-19 epidemic (5).

The cloud model itself combines randomness and fuzziness. It can well simulate the qualitative concept of data representation. Based on the existing data about the mental health of community workers involved in the prevention of COVID-19 epidemic, a cloud model was established to predict the mental health of community workers involved in the prevention of COVID-19 epidemic through single-rule reasoning or multi-rule reasoning. As influenced by various factors, community workers involved in the prevention of COVID-19 epidemic have random and uncertain mental health. The traditional prediction methods have difficulty in process analysis of mental health; however, the development of computer technology and Artificial Intelligent technology can provide a new method of mental health, and cloud model can well predict the mental health of community workers involved in the prevention of COVID-19 epidemic, so it has great research value. Because the cloud model has the advantage of combining randomness and fuzziness, it can improve the prediction effect of mental health of community workers involved in the prevention of COVID-19 epidemic. The proposed prediction model based on cloud model has good feasibility and effectiveness in prediction of mental health. The prediction results can be obtained without an effect of the environment and other factors.

COLLECT DATA ABOUT MENTAL HEALTH OF COMMUNITY WORKERS INVOLVED IN THE PREVENTION OF COVID-19 EPIDEMIC

The specific work of COVID-19 epidemic prevention includes centralized medical observation and quarantine management, quarantined personnel inspection and management, checkpoints on duty for all people entering the city, temperature measurement in communities, disposal of daily wastes, and online mental assistance, etc. About 70% community workers participate in the inspection and management of quarantined personnel, accounting for the highest proportion. About 58.7% community workers participate in more than two of the above tasks, and some community workers even get infected due to contact with suspected COVID-19 patients. About 84.1% of community workers do not know whether there would be corresponding subsidies when accepting the pandemic control task, but they could accept the work arrangement. About 48.5% of community workers could go home every day, but due to the special pandemic control task, they have been away from home for a maximum of 35 days (6).

By scanning a QR code or clicking a link, the community epidemic control workers filled in a questionnaire about their personal information, mental health work, epidemic prevention and control work, and emotions anonymously online. Such method has good validity and reliability for the screening depressive disorders and evaluating depression severity. The questionnaire consists of 9 items designed to understand how much time the patient has been troubled by 9 problems, including depression and decreased interest, in the past 2 weeks. The score of every element is listed as follows: 0 = not at all; 1 = how many days; 2 = more than half of the days; 3 = almost every day. The total score of the scale is 27, and it was depression if the score is more than 5. The scores of 5, l0, 15,

and 20 are the cutoff points for "mild," "moderate," "severe," and "extreme severe" depression, respectively. The nine symptoms of depression in the questionnaire include unhappy mood, anxiety, insomnia, feebleness, anorexia, lack of self-confidence, difficulty in concentrating, irritability, and biased ideas (7).

In addition, a scale of generalized mental problems is designed in the study. The concise self-assessment anxiety scale is developed based on DSM-IV diagnostic criteria for screening for mental problems and assessing the severity of mental health conditions, which has good reliability and validity. The questionnaire consisted of 7 items, which was designed to know how much time the patient has been troubled by problems including "difficult to relax" and "too worried about all kinds of problems" in the past 2 weeks. The scores of every item are listed as follows: 0 = never, 1 = several days, 2 = more than 1 week, 3 = all time. The total score of the scale is 21, and it is anxiety if the score is more than 5. The scores of 5, 10, and 15 represent the boundary values of "mild," "moderate," and "severe" anxiety, respectively. The seven anxiety symptoms in the scale include nervousness, anxiety or eagerness, failure in stopping or controlling worry, worrying too much about everything, difficult to relax, unable to sit still due to anxiety, irritability, and fear of terrible things (8).

Besides, different demographic characteristics, including gender, age, marriage, education, professional title as well as occupation, and working hours, are compared in this study to determine the score of mental health of community workers involved in the prevention of COVID-19 epidemic. According to the mental health status, the respondents were divided into two groups as dependent variables, with age, marriage, education level, and working hours as independent variables. Then, unconditional logistic regression is performed to analyze the correlates of depression and anxiety. COVID-19 has brought great spiritual stimulation to the society, so mental intervention of community workers involved in the prevention of COVID-19 epidemic has become one of the important components of epidemic prevention and control. The situation has caused mental stress in epidemic prevention personnel, even acute stress disorder, and traumatic stress disorder. When acute infectious diseases are prevalent in a certain area, community workers involved in the prevention of COVID-19 epidemic may suffer from various mental problems. Due to the severity and complexity of community epidemic control, the mental health of community workers involved in the prevention of COVID-19 epidemic has been greatly impacted, and they are under tremendous work pressure and mental stress. Therefore, it is necessary to collect COVID-19 gender-specific questionnaires and gather statistics about the mental problems of community workers involved in the prevention of COVID-19 epidemic according to their gender, education level, and occupation. The most common mental emergency reactions of community workers involved in the prevention of COVID-19 epidemic include easy to get fatigue, poor sleep, and difficulty in making decisions, showing that those community workers involved in the prevention of COVID-19 epidemic have experienced health problems and are faced with huge mental problems that they need to receive appropriate mental interventions. Through the analysis of the impact of different gender, occupation, and education on the mental health of community workers involved in the prevention of COVID-19 epidemic, effective mental intervention measures can be adopted (9).

CLOUD MODEL THEORY

Definition and Digital Characteristics of Cloud

The quantity concept is the quantitative concept W, if $x \in W$ is a stochastic implementation of concept, the certainty of x to Y, $W \rightarrow [0,1], x \in W$, and then, distribution of x on W is named as cloud model.$\mu(x)$ reflects the level of certainty that the quantitative value $x$belongs to the qualitative concept Y. Therefore, the cloud model can not only use the membership function $\mu(x)$ and describe the fuzziness of the concept, but also describe the membership function $\mu(x)$ and the randomness of cloud droplets (10, 11).

The digital features of cloud play an important role in cloud model. Among them, expectation E_x illustrates main probability of qualitative concept and is the mathematical expectation of cloud droplets in spatial distribution of universe; entropy E_n illustrates the uncertainty measure of qualitative concept; super entropy H_e illustrates the uncertainty of entropy and shows the level at which the stochastic variable corresponding to qualitative concept deviates from normal distribution.

Cloud Model

Cloud model is an uncertainty transformation model between qualitative concept and quantitative description, which can be used to represent qualitative concept and carry out quantitative calculation. At present, the cloud model has developed from 1D to n-dimensional or even multiple dimensional, so it can be used to represent more complex natural language concepts. In this study, the forward cloud generator implementation algorithm of 1D and 2D cloud model is designed, the cloud model algorithm is implemented with MATLAB language, and the graphics of two different dimensional cloud models are drawn (12, 13).

1D Forward Cloud Generator

The most basic cloud model is 1D normal cloud model, which is most commonly used in expressing qualitative concepts. The algorithm of generating cloud droplets by calculating the digital features E_x, E_n, and H_e of 1D cloud model is called 1D forward cloud generator, and vice versa.

Algorithm 1: implementation algorithm of 1D forward cloud generator (14)

Input: values of three numeric digital features E_x, E_n and H_e of 1D cloud and the number of cloud droplets i (i is a positive integer).

Output: i 2D points (x_i, u_i), which are cloud droplets.

Step 1: Calculate and form a normal arbitrary number x with expected value of E_x and the typical deflection of E_n;

$$x = Normrnd(E_x, E_n) \tag{1}$$

where, *Normrnd* is normal random number generating function.

Step 2: Calculate and generate a normal random number E_n' with expected value E_n and typical deflection H_e;

Step 3: Calculate value of u by

$$u = e^{-\frac{(x-E_x)^2}{2E_n'^2}} \tag{2}$$

Step 4: Repeat i times of calculation steps (1) -(3), and $i$cloud drops (x_i, u_i) are generated.

2D Forward Cloud Generator

(c) 2D cloud model is developed based on 1D model. Its numerical characteristics are six values (E_x, E_{nx}, H_x, E_y, E_{ny}, H_y) (15).

(d) Algorithm 2: Algorithm of 2D forward cloud implementation

(e) Input: 2D normal cloud model is represented by three numbers. Its main parameters are (E_x, E_{nx}, H_x, E_y, E_{ny}, H_y) and the number of cloud droplets is n.

(f) Output: the number of 3Dl cloud drop coordinates with number of n, respectively, is (X_n, Y_n, U_n).

Step 1: The value of (X_i,Y_i) is calculated by the following expression:

$$(X_i, Y_i) = Pnormrnd(E_x, E_{nx}, E_y, E_{ny}) \tag{3}$$

where $Pnormrnd$ is two-dimensional random number generation function. It can be used to form 2D normal stochastic number (X_i,Y_i) with expected vale of (E_x,E_y) and standard variance of (E_{nx}, E_{ny}).

Step 2: The value of (E_{nxi},E_{nyi}) is calculated as:

$$E_{nxi}, E_{nyi} = pcg(E_{nx}, H_x, E_{ny}, H_y) \tag{4}$$

Step 3: The value of $U_i$is calculated as:

$$U_i = e^{-\frac{1}{2}[\frac{(X_i-E_x)^2}{E_{nxi}^2}+\frac{(Y_i-E_y)^2}{E_{nyi}^2}]} \tag{5}$$

Step 4: Repeat n times of calculation steps 1–3, and $n$cloud drops (X_n, Y_n, U_n) can be formed.

MENTAL HEALTH PREDICTION MODEL FOR COMMUNITY WORKERS INVOLVED IN THE PREVENTION OF COVID-19 EPIDEMIC BASED ON CLOUD THEORIES

Language Prediction Rules Based on Cloud Model

Cloud model can effectively realize the transition between quantitative values and corresponding qualitative concepts, represent qualitative concepts through corresponding rule generators, and realize uncertain reasoning between different concepts. **Figure 1** shows the cloud language prediction rules based on the conditional cloud generator (16, 17).

In **Figure 1**, the connection between X-condition cloud generator and Y-condition cloud generator constitutes the corresponding cloud language prediction rules, and its corresponding algorithm is as follows (18):

Step 1: According to the qualitative concept $C_A(E_{xA}, E_{nA}, H_{eA})$ of Xconditional cloud generator, a normally distributed random number $E_{nA}^{'} = Norm(E_{nA}, H_{eA}^2)$ is generated;

Step 2: Calculate the membership degree of the specific input value x of the X condition cloud generator by

$$u = e^{-\frac{(x-E_{xA})^2}{2E_{nA}^2}} \tag{6}$$

Step 3: According to the qualitative concept $C_B(E_{xB}, E_{nB}, H_{eB})$ of - conditional cloud generator, a normally distributed random number $E_{nB}^{'} = Norm(E_{nB}, H_{eB}^2)$ is generated;

Step 4: Calculate the output of a specific input value x. If $x < E_{xA}$, the input is at the rising edge of the conditional cloud, and $b = E_{xB} - E_{nB}^{'}\sqrt{-2\ln u}$; otherwise, it is at the falling edge, $b = E_{xB} + E_{nB}^{'}\sqrt{-2\ln u}$.

To realize the uncertainty reasoning from qualitative concept $C_A(E_{xA}, E_{nA}, H_{eA})$ to qualitative concept $C_B(E_{xB}, E_{nB}, H_{eB})$, for the specific input value x in universe U_A, the X conditional cloud generator randomly generates its corresponding uncertainty u and transfers the uncertainty of qualitative concept A to universe U_B. The Y conditional cloud generator generates and outputs a random cloud drop $drop(b, u)$ under the control of uncertainty u, so the output value b of Yconditional cloud also has uncertainty. In other words, the transmission of uncertainty is realized in cloud reasoning.

Cloud Model Representation of Concepts Related to Mental Health Prediction of Community Workers Involved in the Prevention of COVID-19 Epidemic

Community Workers Involved in the Prevention of COVID-19 Epidemic

To predict the failure of power transmission and transformation equipment, it is necessary to input the historical data of power transmission and transformation equipment and build a cloud reflecting the two related qualitative concepts of the mental health and the possibility of mental obstacles of community workers involved in the prevention of COVID-19 epidemic using the reverse cloud generator (19). If the input data are more than 10 groups, the expected value obtained has high accuracy and small error. Therefore, the mental health data of 10 groups of community workers involved in the prevention of COVID-19 epidemic were used in this study.

Set X as statistical mean of mental health index of community workers involved in the prevention of COVID-19 epidemic in the year related to maximum equipment failure ratio, and $u(x)$ as the level at which a certain mental health index x_i of equipment belongs to mean value X of mental health index in the community with most serious mental disorders. Therefore, the membership

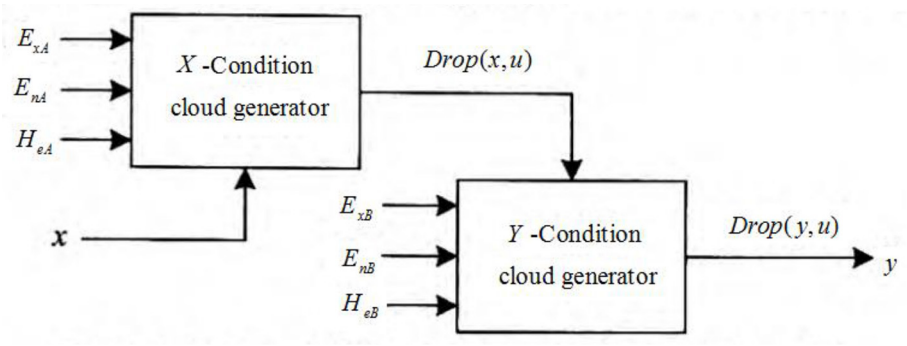


FIGURE 1 | Cloud language prediction rules based on uncertain reasoning.

computing means of mental health parameter of the community workers involved in the prevention of COVID-19 epidemic are (20).

$$u(x) = \begin{cases} \frac{x_i}{X}, \text{when } x_i < X \\ 1, \text{when } x_i \geq X \end{cases} \tag{7}$$

To form the trend cloud of mental health status of community workers involved in the prevention of COVID-19 epidemic in the corresponding state, it is assumed that $p_i(i = 1, 2, \cdots, 10)$ is the mental health level of 10 groups of community workers involved in the prevention of COVID-19 epidemic. P is the level with the most serious mental problems of epidemic prevention workers in 10 communities, $u(p)$ is the mental health level p_i of pandemic control workers in one community, which belongs to the degree of the maximum mental health level P of pandemic control workers in 10 groups of data. Then, the following expression can be obtained:

$$u(p) = \begin{cases} \frac{p_i}{P}, \text{when } p_i < P \\ 1, \text{when } p_i \geq P \end{cases} \tag{8}$$

After reverse cloud generator is applied, historical data and appropriate membership mentioned above are inputted to form numeric features of 3D cloud models, respectively, and status-related cloud $C_A(E_{xA}, E_{nA}, H_{eA})$ illustrating the mental health status of corresponding power transmission and transformation equipment and the fault trend cloud $C_B(E_{xB}, E_{nB}, H_{eB})$ illustrating possibility of fault occurrence have got.

The algorithm of the reverse cloud generator is as follows:

Step 1: Based on normal cloud expectation curve expression $y = e - \frac{(x-E_x)^2}{2E_n^2}$, known cloud droplets can be used to get $E_x^{\wedge}$ by fitting operation;

Step 2: Eliminate points with $y > 0.999$, leaving m cloud drops;

Step 3: Calculate $E_n^{\wedge}$ by the following expression:

$$E_n^{'} = \frac{|x - E_x^{\wedge}|}{\sqrt{-2\ln y}} \tag{9}$$

Step 4: Calculate $H_e^{\wedge}$ by the following expression:

$$H_e^{\wedge} = \frac{\sqrt{\sum_{i=1}^{m} (E_{ni}^{'} - E_n^{\wedge})^2}}{\sqrt{m-1}} \tag{10}$$

Take the state association cloud $C_A(E_{xA}, E_{nA}, H_{eA})$ and fault trend cloud $C_B(E_{xB}, E_{nB}, H_{eB})$ as the qualitative concept cloud and cloud reasoning rules corresponding to X condition cloud and Y condition cloud, so as to realize the reasoning and prediction of mental health status of community workers involved in the prevention of COVID-19 epidemic.

Step 1: Collect historical reliability data and state prediction data;

Step 2: Define the calculation method of conditional cloud membership to form input cloud droplets;

Step 3: Based on the reverse cloud generator, the state correlation cloud and the current trend cloud of mental disorders of community workers involved in the prevention of COVID-19 epidemic are generated;

Step 4: Conditional cloud interconnection constitutes a cloud prediction reasoning model;

Step 5: Calculate the mental health level of community workers involved in the prevention of COVID-19 epidemic under the current state, and judge whether it is >0, if the mental health level is larger than 0, the predicted mental health level is output, otherwise, return to Step 4.

MENTAL HEALTH PREDICTION SIMULATION FOR COMMUNITY WORKERS INVOLVED IN THE PREVENTION OF COVID-19 EPIDEMIC

Community workers involved in the prevention of COVID-19 epidemic have various mental problems. In this research, the mental health level of community workers involved in the prevention of COVID-19 epidemic is predicted at all levels. w is defined as the mental health level of community workers involved in the prevention of COVID-19 epidemic and $s(w)$as the validity

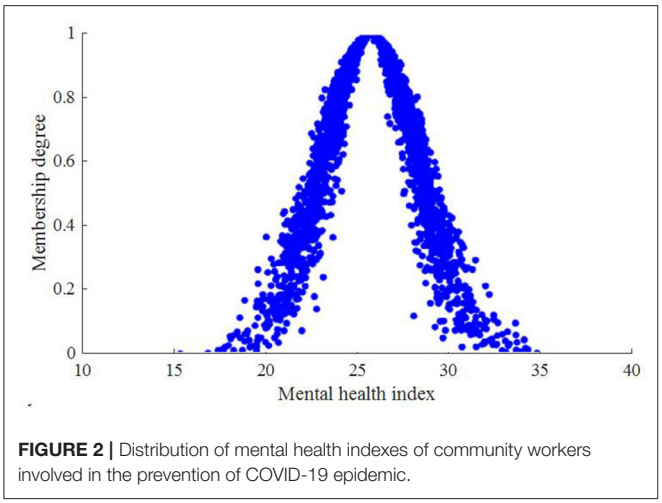


FIGURE 2 | Distribution of mental health indexes of community workers involved in the prevention of COVID-19 epidemic.

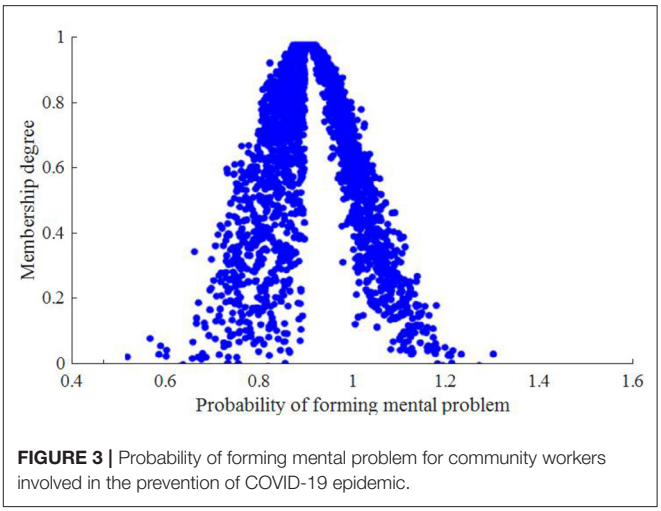


FIGURE 3 | Probability of forming mental problem for community workers involved in the prevention of COVID-19 epidemic.

function of mental health level of community workers involved in the prevention of COVID-19 epidemic, i.e., the severity of mental problems.

The preference utility function meets the requirements of $s'(w) > 0$ and $s''(w) > 0$, that is, the degree of mental disorder increases and the severity of mental problems increases faster, which is in line with the actual situation of mental health of community workers involved in the prevention of COVID-19 epidemic. Therefore, this paper uses the preference utility function to represent the fault severity ($\gamma = 1$).

$$S(w) = 0.576(e^w - 1) \tag{11}$$

The mental health level is defined as the product of the probability of mental disorder and the consequences of mental problem, which is expressed by

$$R = 0.576P \cdot (e^w - 1) \tag{12}$$

where R denotes the mental well-being level value, P denotes the probability of mental problem.

A community is selected to as the research object. The mental problem of community workers involved in the prevention of COVID-19 epidemic mainly concludes force, interpersonal sensitivity, depression, anxiety, hostile, phobic paranoid, psychotic, and sleeping state. According to the above method, the mental health index status correlation cloud and current mental problem trend cloud of community workers involved in the prevention of COVID-19 epidemic are $C_A(22.4, 5.043, 0.325)$ and $C_B(0.325, 0.325, 0.032)$, respectively. Since a cloud drop in cloud model is only the quantitative implement of related qualitative concept, the more cloud drops are, the more they can show whole features of corresponding qualitative concept. Here, 600 predicted cloud drops are formed based on numeric features of the cloud stochastically, and corresponding cloud dispersion distribution is obtained, as shown in **Figures 2**, **3**.

The analysis results show that expected value of mental health index of community workers involved in the prevention of COVID-19 epidemic is related to the expected value of mental disorders. When the mental health index is 25.6, the corresponding probability of forming mental problem is 0.93.

TABLE 1 | Probability of psychological well-being problem and psychological well-being index.

Mental problem	Probability of mental problem	Mental health index
Force	0.24	32
Interpersonal sensitivity	0.32	25
Depression	0.43	27
Anxiety	0.37	26
Hostile	0.42	36
Phobic paranoid	0.26	18
Psychotic	0.22	22
Sleeping state	0.29	34

The probability of forming mental problems and mental health index is as shown in **Table 1**.

The calculation results show that the prediction results of mental health of community workers involved in the prevention of COVID-19 epidemic are in line with the statistical law of mental problems of community workers involved in the prevention of COVID-19 epidemic, and the prediction error is less than 5%. The prediction of mental health level in this study is mainly applied to the mental intervention of community workers involved in the prevention of COVID-19 epidemic, and the accuracy meets the requirements. The traditional method is used to predict mental health of the same samples, and the prediction error is greater than 5%; therefore, the proposed in this paper is better than traditional methods.

CONCLUSIONS

In this study, a method to predict the mental health level of community workers involved in the prevention of COVID-19 epidemic is proposed based on cloud prediction model. Mental problems of community workers involved in the prevention

of COVID-19 epidemic are caused by many uncertain factors, which are random and fuzzy. In this study, a cloud model is applied to the uncertain reasoning prediction of mental problems of community workers involved in the prevention of COVID-19 epidemic, and the cloud language prediction rules based on conditional cloud generator are constructed. A model to predict the mental health level of community workers involved in the prevention of COVID-19 epidemic is established based on cloud reasoning. According to the utility theory, a set of prediction index system of mental health level is proposed, including compulsion, interpersonal sensitivity, expression, anxiety, hostile, phobic paranoia, psychosis, and sleeping state. The mental problem prediction method proposed in this paper can scientifically and reasonably predict the mental health level of community workers involved in the prevention of COVID-19 epidemic and comprehensively and objectively analyze the mental problems of community workers involved in the prevention of COVID-19 epidemic. Therefore, the method can well promote the smooth progress of COVID-19 epidemic prevention and control at the community level.

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

JH is in charging of writing and data analysis.

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frontiers | Frontiers in Public Health

ORIGINAL RESEARCH
published: 28 June 2022
doi: 10.3389/fpubh.2022.880951

Research on the Current Situation and Countermeasures of Inpatient Cost and Medical Insurance Payment Method for Rehabilitation Services in City S

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Objective: This study aimed to introduce bed-day payment for rehabilitation services in City S, China, and analyze the cost of inpatient rehabilitation services. Key issues were defined and relevant countermeasures were discussed.

Methods: The data about the rehabilitation cost of 3,828 inpatient patients from June 2018 to December 2019 was used. Descriptive statistics and the Kruskal–Wallis test were employed to describe sample characteristics and clarify the comparity of cost and length of stay (LOS) across different groups. After normalizing the distribution of cost and LOS by Box–Cox transformation, multiple linear regression was used to explore the factors influencing cost and LOS by calculating the variance inflation factor (VIF) to identify multicollinearity. Finally, 20 senior and middle management personnel of the hospitals were interviewed through a semi-structured interview method to further figure out the existing problems and countermeasures.

Results: (1) During 2015–2019: both discharges and the cost of rehabilitation hospitalization in City S rose rapidly. (2) The highest number of discharges were for circulatory system diseases (57.65%). Endocrine, nutritional, and metabolic diseases were noted to have the longest average length of stay (ALOS) reaching 105.8 days. The shortest ALOS was found to be 24.2 days from the diseases of the musculoskeletal system and connective tissue. Neurological, circulatory, urological, psychiatric, infectious, and parasitic diseases were observed to be generally more costly. (3) The cost of rehabilitation was determined to mainly consist of the rehabilitation fee (23.63%), comprehensive medical service fee (22.61%), and treatment fee (19.03%). (4) Type of disease, age, nature of the hospital, and grade of the hospital have significant influences both on cost and LOS ($P < 0.05$). The most critical factor affecting the cost was found to be the length of stay (standardized coefficient = 0.777). (5) The key issues of City S's rehabilitative services system were identified to be the incomplete criteria, imperfections in the payment system, and the fragmentation of services.

Conclusions: Bed-day payment is the main payment method for rehabilitation services, but there is a conflict between rapidly rising costs and increasing demand

OPEN ACCESS

Edited by:
Fu-Sheng Tsai,
Cheng Shiu University, Taiwan

Reviewed by:
Simon Grima,
University of Malta, Malta
Kazumitsu Nawata,
Hitotsubashi University, Japan

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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *22 February 2022*
Accepted: *24 May 2022*
Published: *28 June 2022*

Citation:
Tang DF, Bian JW, He MH, Yang N and Zhang D (2022) Research on the Current Situation and Countermeasures of Inpatient Cost and Medical Insurance Payment Method for Rehabilitation Services in City S. Front. Public Health 10:880951. doi: 10.3389/fpubh.2022.880951

for rehabilitation. The main factors affecting the cost include the length of stay, type of disease, the grade of the hospital, etc. Lack of criteria, imperfections in the payment system, and the fragmentation of services limit sustainability. The core approach is to establish a three-tier rehabilitative network and innovate the current payment system.

Keywords: rehabilitation, bed-day payment method, hospitalization cost, rehabilitative service delivery system, three-tier rehabilitative network

INTRODUCTION

Rehabilitation allows individuals with health problems to improve their functional status and reduce disability through interventions that interact with the environment (1). Thus, improving the accessibility and affordability of rehabilitation services is essential for maintaining the population's health (2). With the accelerated aging of people and changes in the disease spectrum, the demand for rehabilitation continues to increase (3). Alarcos Cieza et al. (4) estimated that one-third of the world's population will need rehabilitation. The rapid growth in demand will inevitably create challenges for health care systems and health insurance, hence, the WHO in 2017 called to establish ten priority action areas, including the inclusion of rehabilitation in the universal health coverage, the establishment of a comprehensive rehabilitation services model, and the expansion of financing (5). Developed countries are at the forefront of the world's response to this issue (6–8). In 2002, the United States introduced a prospective payment system taking various factors, including patient diagnosis, functional status, age, and co-morbidities into consideration, to limit the cost increase and improve the quality of rehabilitation (9). Thus, a new payment system named FRGs based on the patient's functional status was developed (10). Another prospective payment system developed by GMS is Resource Utilization Groups (RUGs). Patients with similar resource utilization characteristics are divided into a group, and the case portfolio index or payment weight is calculated for each group. The facilities get payment based on their resource utilization (11). To constrain costs more effectively, Patient-Driven Payment Model (PDPM) was developed further. Patients are divided into groups according to clinical characteristics, such as main disease type and complications, and disability and dementia situations (12, 13). Australia and the UK have also developed different case groups and strategies for rehabilitation to better promote rehabilitation development (14).

In the dual context of China's comprehensive promotion of the construction of a healthy China and the implementation of a strategy to actively cope with an aging population (15), rehabilitation services are also receiving increased attention from the Chinese policymakers. The National Health Commission of the People's Republic of China pointed out the need to improve the rehabilitation services delivery system and enhance the capacity of rehabilitation services in its "Opinions on Accelerating the Development of Rehabilitation" (16). The Chinese medical insurance is a typical public contract model, so the reform in payment methods from the administration will have great leverage (17). Governments from central to local levels are exploring reasonable payment systems for rehabilitation services to achieve the dual effect of improving quality and efficiency (18–20). Currently, pay for service (PFS) is the main payment option for rehabilitation services in most provinces in China, which easily results in waste of resources and accelerating increase in costs (21). In 2017, the General Office of the central government suggested that bed-day payment could be applied to those rehabilitation services with a long length of stay and relatively stable cost (22). Zhejiang province began to set specific groups in the DRGs system for long-term rehabilitation hospitalization in 2019, taking average length of stay, average daily cost, and quality into account (23).

City S lies to the southeast coast of China, with a population of about 17.56 million in 2020. It is a relatively developed city, hospitals beds per 1,000 persons were 3.58 and physicians per 1,000 persons was 2.43. Now, it is in a dilemma where the medical resources especially quality resources are insufficient and the unmet need of residents for medical service is growing rapidly (24). The Health Security Bureau of City S Municipality (HSBS) realized the importance of rehabilitation earlier. In order to further reduce the economic burden of patients who need long-term rehabilitation, HSBS carried out a series of reforms, which could provide valuable lessons to other places. It started to sign rehabilitation service contracts with general or rehabilitative hospitals to better meet residents' rehabilitation needs in 2009. As of December 2020, HSBS has contracts with 13 hospitals: three of them are public, and ten are private, including three tertiary hospitals, three secondary hospitals, and seven primary hospitals. Patients with the following two conditions are eligible for the contract: vegetative people in a stable condition and needing long-term rehabilitative inpatient care; patients suffering from advanced tumors or cerebrovascular accident sequelae and trauma or needing hospice care (25). From 2015 to 2019, a total of 10,872 patients enjoyed this long-term rehabilitation care service.

The implementation of the program has primarily met the needs of residents for the long-term rehabilitation. Still, it is also facing the dilemma of much unmet demand from residents and excessive cost increases. Improving efficiency and quality has become a pressing problem for policymakers. This study aimed to analyze the cost of inpatient rehabilitation services in City S and discuss ways to improve the medical insurance policy and rehabilitative service delivery system.

MATERIALS AND METHODS

Quantitative Research Methods

Materials

A retrospective study using data from HSBS was performed, selecting patients under the long-term rehabilitation service contracts. The information about cost, disease types (categorized

by ICD 10), and length of stay (LOS) of all the discharges between 2015 and 2019 was provided by HSBS. With the help of HSBS, the data (N = 3,828) from June 2018 to December 2019 was extracted from the patients' electronic medical records of 13 hospitals under the contract after filtering out sensitive information (i.e., name, address). Information about sex, age, detailed cost categories, disease types (categorized by ICD 10), and other information in the medical records were included. Furthermore, the data were processed as follows: (1) exclude cases missing information about cost and length of stay; (2) exclude cases inconsistent with the actual situation, such as cases with length of stay greater than the duration from June 2018 to December 2019. Therefore, 59 cases were excluded and the final sample size was 3,769.

Data Analysis

The source data were entered using EXCEL 16.0 software to establish an independent database. Descriptive statistics were used to analyze the costs and sample characteristics. Due to the non-parametric distribution of data, the Kruskal–Wallis test was used to clarify the comparity of costs and length of stay in the different groups of patients; the multiple linear regression method was used to analyze the influencing factors of hospitalization cost and length of stay. Considering the hospitalization cost and length of stay were not normally distributed according to skewness and kurtosis, the Box–Cox transformation was performed. Variance inflation factor (VIF) was used to identify multicollinearity for the multivariate regression model. No VIF >10 was accepted (26). $P < 0.05$ (two-tailed) was regarded as statistically significant. All the statistical analyses were implemented using the Stata 16.0.

Qualitative Research Methods

To know more about current situation and explore countermeasures, semi-structured interviews were conducted with the middle and senior leaders of five hospitals that had contracts with HSBS. Two of the hospitals interviewed were tertiary hospitals, one was secondary, and two were primary. Besides, three of them were public and two were private. The interviewees included the president, vice president, director of the medical insurance department, and director of the rehabilitation department, for a total of 20 people. A separate interview with each person was conducted face to face and the total time was 720 min. The main contents were about the development status of the rehabilitation business of the hospitals, opinions on the current payment method, and the problems and countermeasures of the rehabilitation system in City S. The whole interviews were recorded, and after the data were compiled and analyzed, key issues were defined.

RESULTS

Sample Characteristics

Among all the 3,769 patients, 66.92% (N = 2,419) were male and 39.98% (N = 1,507) were 40–60 years old. The circulatory system diseases accounted for the largest proportion of 64.02% (N = 2,413). In total, 80.84% (N = 3,047) of patients were from private hospitals, 65.11% (N = 2,454) were from primary hospitals, followed by secondary hospitals with 25.76% (N = 971), and finally tertiary hospitals with 9.13% (N = 344). The cost and length of stay were found to be significantly different ($P < 0.05$) across groups of age, type of disease, nature of the hospital, and grade of the hospital (see **Table 1**).

Cost

Cost From 2015 to 2019

The bed-day payment method was adopted under the rehabilitation service contract. In 2015, all facilities shared the same payment rate and were paid by 80$ per bed-day. In 2016, the payment rate began to take medical service price level into consideration. In City S, the price of inpatient medical services was divided into 3 levels: level 1, which was the standard price and applied to tertiary hospitals; level 2, 95% of level 1 and applied to secondary hospitals; level 3, 90% of level 1 and applied to primary hospitals. Therefore in 2016, the payment rate was divided into 3 classes: 105.6, 112, and 116.8 ($/bed-day). Tertiary hospitals enjoyed a higher rate than secondary or primary hospitals for the same service. The rate was adjusted dynamically and the formula was "payment rate = average inpatient cost of each bed-day in recent 3 years* (1 + basic growth rate)* (1 + inpatient price growth rate)* (1 + price level rate)". In 2019, the payment rates reached 130.4$ for tertiary hospitals, 123.8$ for secondary hospitals, and 117.3$ for primary hospitals (27).

During 2015–2019, the total discharges in City S for inpatient rehabilitation was 10,782 and tended to increase with an average growth rate of 166% each year. During this period, the cost of inpatient rehabilitation increased year by year with an average growth rate of 79.83%, and the growth rates in 2018 and 2019 were both over 100%. In 2015, the cost for inpatient rehabilitation accounted for and 4% of the total expenditure of the city's medical insurance fund, but it became 8.69% in 2019. The average cost per capita in 2015 was only 6,248.56$, while it rose to 7,930.864$ in 2019 (see **Table 2**).

From 2015 to 2019, 57.65% of the discharges were from circulatory system diseases (including cerebral infarction, hypertension, cerebral hemorrhage, and heart failure); neurological system diseases (namely, Alzheimer, enceph alomyelitis, hemiplegia, and epilepsy) accounted for 10.42%; musculoskeletal system and connective tissue diseases (namely, arthrosis, fracture, lumbar disc herniation, and cervical spondylosis), accounting for 6.18%. Overall, neurological, circulatory, urological, psychiatric, infectious, and parasitic diseases were observed to be generally more costly than bone and joint and sports-related diseases. In 2019, certain infectious and parasitic diseases were the costliest diseases and the average cost had reached 9,253.31$. Digestive system diseases were the least costly and the average cost was 2,491.65$ (see **Table 3**).

Cost Structure

The per capita rehabilitation cost for 3,769 patients was calculated to be 7,873.96$ and it mainly consisted of rehabilitation fee (23.66%), comprehensive medical service fee (22.61%), treatment fee (19.03%), Chinese medicine fee (12.54%), medicine fee (12.42%), and diagnosis fee (5.46%). The comprehensive

TABLE 1 | Sample characteristics.

	N (%)	Average cost		*P*-value	Average length of stay		*P*-value
		Mean	SD		Mean	SD	
Sex				0.828			0.659
Male	2,419 (66.92%)	7,955.78	106.12		65	0.81	
Female	1,196 (33.08%)	7,993.53	154.26		65	1.12	
Age				$P < 0.001$			$P < 0.001$
0–20	105 (2.79%)	4,542.39	273.23		41	2.53	
20–40	615 (16.32%)	6,319.15	200.14		53	1.48	
40–60	1,507 (39.98%)	7,800.70	129.69		64	1.02	
60–80	1,072 (28.44%)	8,808.24	166.93		69	1.19	
>80	470 (12.47%)	8,756.73	240.79		72	1.81	
Type of disease				$P < 0.001$			$P < 0.001$
Tumors	169 (4.48%)	5,083.97	350.08		38	2.64	
Mental and behavioral disorders	25 (0.66%)	7,982.80	1,321.22		70	11.72	
Neurological diseases	328 (8.70%)	8,637.93	408.84		70	2.75	
Circulatory system diseases	2,413 (64.02%)	8,446.89	96.58		68	0.73	
Diseases of the skeletal muscle system and connective tissue	245 (6.50%)	2,648.85	96.38		21	0.86	
Injury, poisoning, and certain other results of exogenous effects	147 (3.90%)	8,491.56	342.95		77	2.86	
Factors affecting health status and exposure to health services	194 (5.15%)	6,582.26	323.08		54	2.33	
Other diseases	248 (6.58%)	8,985.65	392.60		75	2.99	
Nature of the hospital				$P < 0.001$			$P < 0.001$
Public	722 (19.16%)	5,796.73	180.93		53	1.70	
Private	3,047 (80.84%)	8,366.18	93.97		67	0.67	
Grade of the hospital				$P < 0.001$			$P < 0.001$
Primary	2,454 (65.11%)	7,373.24	97.69		64	0.77	
Secondary	344 (9.13%)	2,787.64	113.29		22	0.91	
Tertiary	971 (25.76%)	10,941.40	163.69		79	1.17	

TABLE 2 | Cost from 2015 to 2019.

	2015	2016	2017	2018	2019
Inpatient rehabilitation cost (billion, $)	0.03808	0.07904	0.12592	0.15936	0.36
Growth rates	–	107.56%	59.31%	26.56%	125.90%
Share of the total medical insurance fund expenditures	4.00%	6.00%	4.45%	4.03%	8.69%
Average cost per capita ($)	6,248.56	6,681.26	6,989.26	6,965.58	7,930.86

medical service fee mainly contained a general treatment operation fee and a general medical service fee. Non-surgical treatment cost-dominated treatment fee. Overall, the cost for inpatient rehabilitation was mainly consisted of rehabilitation fee and service fee that reflects the labor value of medical and nursing staff. While the cost of drugs, consumables, and diagnostic fee were observed to account for a smaller proportion (see **Table 4**).

Influencing Factors of Cost

The multiple linear regression analysis was performed using inpatient rehabilitation cost (transformed by the Box–Cox model) as the dependent variable. Independent variables were: age, length of stay (LOS), type of disease, nature of the hospital, grade of the hospital, and the out-of-pocket ratio of the cost. The results showed that $F = 721.491$, $P < 0.001$, and adjusted $R^2 = 0.713$, indicating that the regression equation held and fit well. The highest VIF was 5.710 and the model waived the risk of multicollinearity (VIF > 10). LOS, tertiary hospital (compared to primary hospital), circulatory system diseases (compared to tumors), and private hospital (compared to public hospital) were all found to be positively associated with inpatient rehabilitation cost. And the out-of-pocket ratio had a negative effect on inpatient rehabilitation cost. Furthermore, the standardized coefficient of LOS is 0.777, which was the biggest one, and the Pearson's correlation between LOS and inpatient rehabilitation cost was as high as 0.836, indicating LOS was the most influencing factor (see **Table 5**).

TABLE 3 | Average costs for different types of diseases ($).

Type of diseases	Typical diseases	2015	2016	2017	2018	2019
Certain infectious and parasitic diseases	Post-tuberculous encephalopathy	6,947.92	7,123.95	5,196.07	3,208.80	9,253.31
Tumors	Lung cancer, stomach cancer, liver cancer, etc.	3,627.17	2,638.17	4,024.31	4,855.02	5,620.56
Mental and behavioral disorders	cognitive impairment	7,071.46	6,880.04	7,305.12	5,215.90	9,064.15
Neurological disorders	Alzheimer, encephalomyelitis, hemiplegia, epilepsy	5,869.18	6,389.62	7,353.16	7,586.37	8,852.50
Circulatory system diseases	Cerebral infarction, hypertension, cerebral hemorrhage, heart failure	7,184.56	7,099.43	7,677.70	7,549.30	8,527.04
Respiratory diseases	Lung infection, respiratory failure	15,100.24	8,345.45	8,034.11	6,890.39	7,773.47
Digestive system diseases	Gastrointestinal bleeding, intestinal obstruction	0.00	0.00	4,188.03	2,617.77	2,491.65
Diseases of the musculoskeletal system and connective tissue	Arthrosis, fracture, lumbar disc herniation, cervical spondylosis	2,054.28	2,617.73	2,101.95	2,427.30	3,463.80
Genitourinary diseases	Urinary tract infection, chronic renal failure	0.00	0.00	0.00	4,722.78	8,025.73
Signs, symptoms, and clinical and laboratory abnormalities not attributable to other	Difficulty swallowing, loss of consciousness, speech difficulties, fatigue	0.00	0.00	0.00	3,750.78	6,413.54
Injury, poisoning and certain other consequences of external causes	Nerve injury, bone injury, sequelae, etc.	4,559.02	8,945.54	8,816.29	6,914.22	5,582.32
Factors affecting the state of health and the institutional basis with health care	Postoperative recovery period	3,983.71	5,609.91	8,561.38	6,034.52	6,244.50
Diseases of the musculoskeletal system and connective tissue	Arthrosis, fracture, lumbar disc herniation, cervical spondylosis	4,678.45	6,449.54	6,660.24	5,939.43	8,712.82
Other		5,569.87	9,613.88	7,912.82	6,464.61	452.46

Length of Stay

Length of Stay of Different Types of Diseases From 2015 to 2019

The length of stay varied in different types of diseases. Endocrine, nutritional, and metabolic diseases were found to have the longest average length of stay, reaching 105.8 days. Genitourinary diseases reached 72.8 days and the LOS of neurological disorders were 71.9 days, which were relatively longer than other types of diseases. The shortest average length of stay was found to be 24.2 days from the diseases of the musculoskeletal system and connective tissue (see **Table 6**).

Influencing Factors of Length of Stay

Length of stay (transformed by the Cox–Box model) was set as the dependent variable in the multiple regression model. Independent variables were age, out-of-pocket ratio, type of disease, nature of the hospital, and grade of the hospital. The results showed higher age, smaller out-of-pocket ratio, public, and tertiary hospital resulted bigger length of stay. Different types of diseases were all found to be associated with LOS. But, what could not be ignored was that the adjusted R^2 was only 0.252, suggesting other critical factors omitted. The highest VIF was 5.595, and there was no risk of multicollinearity (see **Table 7**).

Key Issues

Of all the interviewees, 75% were male, 35% were 40–45 years old, and 30% had 15–20 working years. There were separately 40% of total interviewees from primary and tertiary hospitals, and 60% were from public hospitals (see **Table 8**). Key issues were defined as followed.

Rehabilitation-related criteria were identified to be incomplete, including patient admission and discharge criteria and grading and classification criteria, which was one of the reasons for the rapid increase in cost. Currently, the admission criteria applicable to the contract were vague, without clear regulations on the type and severity of the disease. It resulted in a mixed composition of patients. A significant number of long-term care and hospice patients, less costly but having a longer stay, were also included. But in the context of bed-day payment, the insurance needed to pay the same amount according to the length of stay, which was much more than the real cost. On the other hand, some patients had long been occupying beds due to the lack of clear discharge criteria, resulting in not only a tight bed capacity but high cost. Grading and classification criteria were needed to strengthen the management of patients and provide a reference for payment. But there was a lack of unified criteria, which brought a great barrier to the refinement of payment and quality improvement.

Single bed-day payment was insufficient to reflect the real resource usage and guarantee equity. Patients with different types of diseases or with the same disease but different degrees of severity were applicable to the same payment rate. For example, patients in critical rehabilitation usually required some surgical treatment and relied on medical instruments so that the cost of whom was much more than other kinds of patients. But the long-term care patients were much less costly, which was the main source of hospitals' profits. Therefore, hospitals might face

TABLE 4 | Composition of per capita rehabilitation medical costs ($).

Item	Detailed item	Amount	Percentage (%)
Comprehensive	General medical services	568.94	7.23
medical services	General treatment operations	732.32	9.30
	Nursing	469.87	5.97
	Other	8.82	0.11
	Total	1,779.96	22.61
Diagnostics	Pathological diagnosis	0.10	0.00
	Laboratory diagnosis	243.11	3.09
	Diagnostic imaging	122.72	1.56
	Clinical diagnosis	63.69	0.81
	Total	429.62	5.46
Treatment	Non-surgical treatment items	1,488.17	18.90
	Surgical treatment	10.28	0.13
	Total	1,498.45	19.03
Rehabilitation		1,862.84	23.66
Chinese medicine		987.76	12.54
Western medicine		874.77	11.11
Traditional Chinese medicine		0.00	1.31
Blood and blood products		103.48	0.16
Consumables		0.00	1.53
Other		12.68	2.59
Total		120.29	100.00

pressure of cost control or room for profit. The equity of payment would be weakened or there might be a risk of patient selection or malpractice that reduced the quality of care. Besides, considering City S is building a separate long-term care insurance, the long-term care patients will be excluded from the rehabilitation service contract. Therefore, hospitals would face greater challenges as the average cost increase greatly.

Rehabilitation service was fragmented and failed to meet the requirements of integrated care. Most rehabilitation facilities interviewed did not have referral agreements with other hospitals, which meant that patients could not get continued care. The linkage between acute care and rehabilitation was not smooth, resulting in some patients missing the best period of rehabilitation. Besides, some rehabilitation patients still had the need for acute care. But the payment of the medical insurance only covered rehabilitation services in single hospitalization, which resulted in the insufficient care for the sake of controlling cost.

DISCUSSION

The data from City S showed that there was a rapid growth in the number of discharges and expenditures from 2015 to 2019, which reflected the strong demand for rehabilitation and suggested that the reform successfully satisfied part of the unmet need. City S encouraged patients in need of rehabilitation services to go to secondary or primary rehabilitation facilities. Thus, there were only 18.51% of patients in tertiary hospitals and the average out-of-pocket ratio was only 8.48%. This provided a good example for other cities or countries to release tight capacity of tertiary hospitals and improve the availability of rehabilitation services. The bed-day payment was also an innovative method compared with paying for service, which was widely used in China (28). It could reduce the waste of medical resources. However, the excessive increasing rate of expenditure, less specific payment system, and fragmented services delivery system cast a doubt on the sustainability. Therefore, there is still much room for improvement.

First, the length of stay should be reasonably controlled. The results showed that the length of stay was the most important factor influencing the growth of rehabilitation expenditure, which is consistent with other studies in China (29–32). To contain the LOS and increase resources' mobilization, diagnosis-related groups (DRGs)-based payments were wildly used in the US and other high-income countries. Hospitals were paid within the predefined scale according to classifications of DRG (33). A new *per diem* inclusive payment system called the DPC/PDPS (diagnosis procedure combination/*per diem* payment system) were adopted in Japan. In total, three periods were specified for each disease along with standardized *per diem* payments for each period and the payments diminish with increasing LOS (34, 35). Italy linked reimbursement to effective stay based on the time to reach peak improvement for different groups of conditions (36, 37). A weighted blended payment model was designed for rehabilitation by Australia, which applies a mixture of the episode and *per diem* rates. The whole rehabilitation was divided into four episodes: short stay (1–3 days), low outliers, inlier range (ALOS +/– 4 days), high outliers, and every episode was attached to a separate *per diem* rate according to the resources use (38). Thus, experience from the developed countries could be taken by City S that set a predefined payment rate based on diagnosis and interventions and makes the rate diminish over LOS.

The payment system needs to be innovated to drive up efficiency. Now, worldwide health systems are increasingly moving toward payment systems based on a fixed tariff structure for each episode of treatment and case-mix classification was adopted to drive up efficiency and to contain costs (39–42). For example, medicare beneficiaries are assigned to case-mix groups (CMGs) considering the diagnosis, age, level of motor, and cognitive function (43). Medicare would pay rehabilitation facilities predetermined per discharge rates based on the CMGs and market area wages (43). Therefore, bed-day payment rates could also be adjusted by diagnosis, grade of the hospital, function, and some other factors related to resources use. Hospitals have the right to negotiate with the medical insurance agency to set the final basic payment rate. Besides, more payment methods could be adopted for different kinds of patients (39). For certain diseases with relatively stable resource usage level, a fixed tariff could be used. For simple services lasting a long time, capitation payment can be used. For some complex services, pay for service is more appropriate. Medicare also made outlier payments when a rehabilitation facility's estimated total costs for a case exceeded a cost threshold. The outlier payment for a case

TABLE 5 | Multiple linear regression analysis of costs for inpatient rehabilitation.

Variables	Unstandardized coefficients		Standardized coefficients B	*t*	Significance	*B* (95.0%CI)		VIF
	Unstandardized coefficients B	SD				Lower limits	Upper limits	
Constant	103.714	3.690		28.107	$P < 0.001$	−8,818.071	−1,037.243	
Age	0.077	0.031	0.023	2.492	0.013	47.681	112.856	1.185
LOS	1.280	0.015	0.777	82.657	$P < 0.001$	626.061	658.970	1.282
Out-of-pocket ratio of costs	−39.290	6.373	−0.052	−6.165	$P < 0.001$	16,917.466	26,522.962	1.040
Type of diseases (**ref: tumors)**								
Mental and behavioral disorders	−9.236	7.171	−0.012	−1.288	0.198	−11,966.512	3,293.346	1.174
Neurological diseases	2.098	3.318	0.009	0.632	0.527	−2,770.556	4,281.780	3.032
Circulatory system diseases	9.970	2.674	0.074	3.728	$P < 0.001$	−2,394.836	3,317.513	5.710
Diseases of the skeletal muscle system and connective tissue	−2.668	4.591	−0.010	−0.581	0.561	−5,598.449	4,157.329	4.440
Injury, poisoning, and certain other results of exogenous effects	0.494	3.839	0.001	0.129	0.898	−8,498.907	−321.162	1.915
Factors affecting health status and exposure to health services	4.798	3.498	0.016	1.372	0.170	−4,702.563	2,742.521	2.070
Other diseases	7.382	3.382	0.028	2.183	0.029	405.959	7,553.403	2.436
Nature of the hospital (ref: public hospital)								
Private school	9.633	1.936	0.059	4.976	$P < 0.001$	2,040.646	6,164.528	2.012
Grade of the hospital (ref: primary school)								
Secondary school	5.417	3.784	0.024	1.432	0.152	−727.382	7,322.108	4.116
Tertiary hospital	24.435	1.338	0.165	18.264	$P < 0.001$	10,445.272	13,445.799	1.186

TABLE 6 | Different diseases' length of stay.

Type	Typical diseases	Average length of stay (ALOS)
Certain infectious and parasitic diseases	Post-tuberculous encephalopathy	61.9
Tumors	Lung cancer, stomach cancer, liver cancer, etc.	41.3
Endocrine, nutritional, and metabolic diseases	Diabetes	105.8
Mental and behavioral disorders	Cognitive impairment	68.3
Neurological disorders	Alzheimer, encephalomyelitis, hemiplegia, epilepsy	71.9
Circulatory system diseases	Cerebral infarction, hypertension, cerebral hemorrhage, heart failure	68.5
Respiratory diseases	Lung infection, respiratory failure	57.2
Digestive system diseases	Gastrointestinal bleeding, intestinal obstruction	28.3
Diseases of the musculoskeletal system and connective tissue	Arthrosis, fracture, lumbar disc herniation, cervical spondylosis	24.2
Genitourinary diseases	Urinary tract infection, chronic renal failure	72.8
Congenital malformations, deformities, and chromosomal abnormalities	Cerebral hypoplasia	52.6
Signs, symptoms, clinical and laboratory abnormalities not attributable to other	Difficulty swallowing, loss of consciousness, speech difficulties, fatigue	68.4
Injury, poisoning, and certain other consequences of external causes	Nerve injury, bone injury, sequelae, etc.	62.1
Factors affecting the state of health and the institutional basis with health care	Postoperative recovery Recovery period	69.8
Other		40.8

was equal to 80% of costs above this threshold (44). Therefore, for some rehabilitation patients with high-medical demand that are extraordinarily costly compared with the other cases, a outlier payment is also needed. The over costly medical service provided during the hospitalization could be assigned to DIP (diagnosis-intervention packet) payment, which is a novel case-mix with a global budget payment system developed by China (45). Finally, a quality-based payment system for rehabilitation services should be further explored after various standards and assessment systems being improved.

Various criteria need to be developed and insurance management should be strengthened. Clear admission and discharge criteria are necessary to increase efficiency and enhance effectiveness. For example, CMS specified 13 qualifying

TABLE 7 | Multiple linear regression analysis of length of stay.

Variables	Unstandardized coefficients		Standardized coefficients B	*t*	Significance	*B* (95.0%CI)		VIF
	Unstandardized coefficients *B*	SD				Lower limits	Upper limits	
Constant	9.970	0.503		19.826	$P < 0.001$	37.740	53.043	
Age	0.030	0.004	0.108	7.103	$P < 0.001$	0.176	0.306	1.166
Out-of-pocket ratio of costs	−4.533	0.883	−0.074	−5.135	$P < 0.001$	−39.377	−12.287	1.037
Type of diseases(ref: tumors)								
Mental and behavioral disorders	3.827	0.993	0.059	3.852	$P < 0.001$	22.505	55.997	1.170
Neurological diseases	5.407	0.454	0.288	11.920	$P < 0.001$	29.371	43.195	2.943
Circulatory system diseases	4.240	0.367	0.385	11.541	$P < 0.001$	19.246	30.358	5.595
Diseases of the skeletal muscle system and connective tissue	4.035	0.634	0.188	6.361	$P < 0.001$	15.037	35.118	4.401
Injury, poisoning, and certain other results of exogenous effects	4.923	0.529	0.180	9.305	$P < 0.001$	21.661	37.636	1.888
Factors affecting health status and exposure to health services	3.166	0.484	0.132	6.542	$P < 0.001$	10.059	24.713	2.058
Other diseases	6.038	0.461	0.283	13.103	$P < 0.001$	36.220	50.360	2.349
Nature of the hospital(ref: public hospital)								
Private school	−2.478	0.265	−0.184	−9.366	$P < 0.001$	−25.192	−17.072	1.952
Grade of the hospital(ref: primary school)								
Secondary school	−8.285	0.508	−0.451	−16.317	$P < 0.001$	−67.829	−51.321	3.848
Tertiary hospital	2.408	0.182	0.199	13.223	$P < 0.001$	13.435	18.957	1.142

medical conditions for inpatient rehabilitation facilities to distinguish rehabilitation services from acute care, including stroke, spinal cord injury, amputation, etc. (44). A scientific function assessment system is also needed because it is the basis of clarifying patients' needs and providing services reasonably (37). Establishing a third-party assessment committee to independently conduct a dynamic assessment, and the results could be used in the admission and discharge criteria or to evaluate hospitals' service quality. It also could be an important reference for payment. Finally, clinical paths could be introduced to efficiently manage hospitalization schedules (46), ensuring standardization of service.

To promote the integration of the rehabilitation service, a three-tier rehabilitative network should be built, including tertiary hospitals, secondary general hospitals or stand-alone rehabilitative centers, and community health facilities or primary hospitals. Although City S made some meaningful explorations about integrated care (47), the reforms were centered in acute care with less attention paid to the rehabilitation service delivery system. The UK has developed a three-tiered model of local, district, and regional services. More specifically, Level 1 services are discrete tertiary specialized rehabilitation services. Level 2 services are discrete specialist rehabilitation services. Level 3 services are local non-specialist rehabilitation services (39). In China, the tertiary hospitals could be the regional center delivering early rehabilitative services and responsible for the training of talents. Secondary hospitals or stand-alone rehabilitative centers provide post-acute rehabilitation. Primary hospitals or community health facilities are mainly for patients in stable conditions or needing long-term care and provide continuous services. Different levels of facilities should cooperate with each other and form a rehabilitative consortium. These facilities as a whole can provide whole-life services for patients under the guidance of patient-centered philosophy on the basis of two-way referral programs. What is more, now in China there are too many patients staying in tertiary or secondary hospitals and reluctant to go to primary hospitals (31), exacerbating the strain on rehabilitative resources. The policy must guide the flow of patients to primary rehabilitation facilities. Some measures could be taken, such as increasing the reimbursement rate of primary rehabilitative facilities and so on.

CONCLUSION

City S has set a good example for other low- and middle-income countries to satisfy the unmet need for rehabilitation services. It also provided evidence for how the bed-day payment method worked to drive up efficiency. But there is a conflict between rapidly rising costs and increasing demand for rehabilitation. After identifying length of stay as the most important factor affecting cost, key issues were defined about current payment method and rehabilitation service delivery system. To contain cost and drive-up efficiency, the core approaches are to establish a three-tier rehabilitative network and innovate current payment system through introducing a classification system based on diagnosis and interventions, making the payment rate diminish over LOS and biding a mixed payment system.

LIMITATIONS AND PROSPECTS

Only service providers were interviewed in our study, while other stakeholders' opinions especially the patients, did not

TABLE 8 | Demographic information of interviewees.

Characteristics	Frequency	Percent(%)
Gender		
Female	5	25
Male	15	75
Age		
35–40	5	25
40–45	7	35
45–50	6	30
50–55	2	10
Position rank	5	25
President		
Vice president	5	25
Director of Medical Insurance Section	5	25
Director of Rehabilitation	5	25
Working years	3	15
5–10		
10–15	5	25
15–20	6	30
20–25	1	5
25–30	4	20
30 above	1	5
Hospital grade	8	40
Tertiary		
Secondary	4	20
Primary	8	40
Hospital nature	12	60
Public		
Private	8	40

receive enough attention. Due to the quality of data, the longitudinal changes of fees in different categories could not be analyzed and some key factors influencing LOS were omitted. In the future, we hope to comprehensively analyze the problems of the current rehabilitation system from the perspectives of management, supply and demand sides. Besides, more factors influencing cost and LOS would be explored if high-quality data are available.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because of privacy and ethical restrictions. Requests to access the datasets should be directed to zhang.dan@sz.tsinghua.edu.cn.

AUTHOR CONTRIBUTIONS

DT and DZ contributed to the conception of the study. DT, MH, JB, and DZ wrote the first draft of the manuscript and collected and analyzed the samples. DZ and NY consulted on data collection and analysis. DZ reviewed the manuscript and polished it. All authors contributed to the article and approved the submitted version.

FUNDING

This work was supported by Youth Fund of the National Natural Science Foundation of China (Grant No. 72004112) and Shenzhen Educational Science 2020 Annual Planning Project (Grant No. ybzz20034). This work was also supported by Shenzhen key Research Base of Humanities and Social Sciences for Social Governance and Innovation Research, and People's Livelihood & Happiness Benchmarking Study (Grant No. 202003).

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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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frontiers | Frontiers in Public Health

ORIGINAL RESEARCH
published: 05 July 2022
doi: 10.3389/fpubh.2022.953478

The Influence of Knowledge Management Capacities on Pharmaceutical Firms Competitive Advantage: The Mediating Role of Supply Chain Agility and Moderating Role of Inter Functional Integration

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Edited by:
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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *26 May 2022*
Accepted: *13 June 2022*
Published: *05 July 2022*

Citation:
Hu Z, Sarfraz M, Khawaja KF, Shaheen H and Mariam S (2022) The Influence of Knowledge Management Capacities on Pharmaceutical Firms Competitive Advantage: The Mediating Role of Supply Chain Agility and Moderating Role of Inter Functional Integration. Front. Public Health 10:953478. doi: 10.3389/fpubh.2022.953478

This study investigates the factors such as knowledge management capacities and their positive influence on firm competitive advantage or the supply chain agility of the firm and the underlying mechanisms (supply chain agility) that facilitate the firm's performance and leads to firm competitive advantage. It also explores the moderating role of inter-functional integration. We have collected the data from the 308 supply chain managers of pharmaceutical firms in Pakistan and questionnaires were used for data collection with multi-item scales already developed and validated. The findings suggest that knowledge management capacities significantly influence a firm's competitive advantage or supply chain agility. The supply chain agility fully mediates between absorptive capacity, transformative capacity, and firm competitive advantage. Further, supply chain agility partially mediates between inventive capacity and firm competitive advantage. Meanwhile, inter-functional integration moderates the relationship between supply chain agility and firm competitive advantage, with their positive relationship strengthening when inter-functional integration is high. The study provides empirical evidence that knowledge management capacities (such as absorptive capacity, transformative capacity, and inventive capacity), supply chain agility, and inter-functional can be important factors in improving firm performance.

Keywords: absorptive capacity, transformative capacity, inventive capacity, supply chain agility, inter-functional integration, competitive advantage, resource-based view theory

INTRODUCTION

Over the years, competitive knowledge in the new economy has altered the business landscape, thus becoming a critical ingredient for gaining advantage. The increase in globalization and competition has lead global industries to utilize knowledge as a strategic business asset to foster firms' competitiveness. In today's fast-growing environment, knowledge plays a fundamental role in firms' competitive development. Knowledge is a valuable resource that helps a business quickly respond to market changes, gaining a substantial competitive advantage (CA) as a result (1).

In particular, firms perform better than competitors on the basis of valuable knowledge. In recent decades, knowledge has become a valuable asset for firms on the basis that a firm can survive and target their competitors and achieve CA (2). However, in such a competitive time, it is noteworthy that knowledge works as a competitive weapon, managing business uncertainty.

A firm needs knowledge that helps them to respond quickly to market changes and adopt changes frequently at the right time. Changing market trends allow firms to pay greater attention to KM (3). KM is a set of dynamic capabilities of a firm to gather valuable information and then send it across the units of the firm to improve operations internally (4). These dynamic capabilities allow a firm to update and redesign their process with changing market trends. KM is the precise treatment of learning and potential information (5). It is important since it surveys the company's capacity to recognize, absorb, change, and apply profitable external as well as internal information to their procedures or activities to gain an upper hand.

KM is essential because of the growing need to develop a competitiveness capacity to compete in a world economy. Accordingly, today, business landscapes have experienced vast and rapid changing market trends, causing numerous organizations to invest in KM practices. The turbulent market uncertainties have elevated the need for developing novel KM capabilities to combat the emerging business challenges. Realizing the underlying significance of a firm's KM capability has created a reflex in the organizational processes whereby information and knowledge have fundamentally become the catalysts for the development of CA. Given this explanation, the literature indicates that knowledge assets create value for the firm, thereby becoming the prime determinant of superior CA (6).

With the increasing research in the KM domain, supply chain agility (SGA) as a mechanism that explains the relationships between KM capacity and firm outcomes has received more attention, with management adopting KM practices to achieve business competitiveness. In this regard, organizations view gaining a CA as imperative to the operation of the supply chain management process. As such, SGA has emerged as a strategic capability for improving firms' performance and competitiveness (7). Effective supply chain orientation provides distinctive CA to firms. In explaining this notion, the research states that it enables organizations to meet market demands by effectively synthesizing firms' capabilities and competitiveness (8). Undoubtedly, knowledge plays an important role as it is an intangible resource for a firm. It is believed that knowledge management capacities may help a company to enhance the agility of its supply chain and due to SCA, a firm may gain CA. While numerous studies address SGA but very few studies have examined it as mediator, and there is little research on the factors that impact SCA. In addition, there is still a lack of studies in the context of KM and its influence on SCA (9).

Therefore, the present study aims to expand the existing KM literature by investigating the KM capacities of firms, such as their Absorptive capacity (AC), Transformative capacity (TRC), and Inventive capacity (INVC), and their influence on firm CA. The purpose of the research is to identify the influence of KM capacities on firm CA. The research also investigates the mechanism of SCA through which the enterprise gains a CA. Furthermore, the study considers the role of inter-functional integration (INTF) as a moderator between SGA and the CA of the firm.

Significantly, this study makes an important theoretical contribution to the role of the SCA of the firm. This study is unique in exploring several aspects. It considers how KM capacities affect a firm's CA and also how KM capacities impact SCA. The previous research examines the mediating impact of SCA between AC and company performance (10). Therefore, this research examines the mediating role of SCA between KM capacities and firm CA for the first time. The current research also examines the moderating role of inter-firm integration between SCA or firm CA for the first time. To date, there is no research on KM capacities and their influence on SCA and firm CA. Therefore, this current study fills a gap in the literature by investigating the INTF between SCA and CA for the first time.

The findings of the current research provide direction to supply chain managers to overcome continuous challenges by applying effective KM. The combination of these three knowledge capacities (AC, TRC, and INVC) will help managers understand which contributes most to their firm's outcomes. Further, the present study will provide direction to managers to retain focus on INTF as it becomes a major issue. It will benefit the company by drawing their attention to this crucial problem and allowing them to understand that overcoming this problem is essential for the company to succeed, by speeding up the SCA and achieving CA.

This study consists of six different sections. The introduction section illustrates the study's purpose, the research objectives, and significance. Section Literature Review demonstrates the hypothesis development, while Section Literature Review outlines the research methodology. Section Results explains the study outcomes, and Section Discussion compares those outputs with the previous literature. Lastly, Section Conclusion concludes the research topic by explaining the study's limitations and implications.

LITERATURE REVIEW

Knowledge Management Capacities and Competitive Advantage

An organization can achieve CA by having valuable resources that help in achieving firm performance; these resources can be tangible or intangible (11). In today's global competition, a business survives on not only by having tangible resources but also needs to have intangible ones. The fast-growing nature of modern business competition exists on the basis on intangible resources such as valuable information, i.e., the knowledge that can help in achieve performance quickly. In this manner, a firm with strong KM may respond significantly more successfully to clients' needs with new or adjusted products and compete with their competitors at the right time to gain a powerful position in business (12). Indeed, KM has emerged as a key strategic tool to manage firms' competitive performance. Given the articulation,

the study shows that knowledge is a significant factor that encourages the firm to achieve competitive benefit over others (13). Notably, knowledge management is a prime determinant of firms' competitiveness. In explaining this notion, the study states that knowledge management profoundly accelerates the firms' performance, thereby obtaining superior competitive benefits (14).

Global organizations have started developing knowledge as a strategic resource for gaining business competitiveness. In the modern era, this realization has caused organizations to acquire knowledge effectively to attain a superior CA (15). In explaining this notion, the research states that strong market competition has lead organizations to try to gain a CA by improving their KM practices (16). As such, the current study proposes the following hypothesis.

Absorptive Capacity and Competitive Advantage

Absorptive capacity (AC) is a firm's ability to explore information externally or to search for information from an external source outside the firm's boundaries (17). In recent years, many organizations have faced undeniable market challenges, thus bolstering the need to maintain a competitive position. In this regard, AC has emerged as a successful innovation, thereby providing competitive benefit. AC helps firms tackle market uncertainties to gain a CA (18). Moreover, the literature states that a company's AC strengthens the firm's knowledge process, substantially providing the firm with a CA (19). Significantly, AC is an effective means of gaining a competitive advantage. The absorptive capacity contributes to the firm's performance, thereby accelerating the firm's market dominance. Accordingly, in further explaining this relation, the research reveals that AC improves organizational capabilities and competitiveness (20). Undoubtedly, the idea of the absorptive capacity popularized by various researchers had realized AC as a fundamental tool fostering the firms' competitiveness. Given the illustration, the study reveals that absorptive capacity promotes the firms' internalization, thus gaining a competitive advantage (21). Hence, the literature states that organizations should develop their AC to achieve CA (22). As such, the current study proposes the following hypothesis:

H1(a): Absorptive capacity positively influences firm competitive advantage

Transformative Capacity and Competitive Advantage

Transformative capacity (TRC) is the ability of a company to generate knowledge internally or to acquire information from past experiences and skills that the people of the firm possess over time (23). The previous literature found that the practice of KM is the selective application of information from prior decisions or experiences to current and future decision-making procedures (24). Empirical evidence shows increasing openness toward knowledge that is gained from past experiences on which a decision is made to improve firm performance (25). company can attain CA by having prior knowledge, experience, and skills that will add to the knowledge base and help in decision making regarding what is needed for the firm to improve its internal processes, products, and services (26).

However, in the era of the knowledge revolution, the firms' transformative capacities have profoundly contributed to achieving the firms' competitiveness. In recent years, knowledge transfer has elevated the transformation capacities to improve firms' competitiveness. The transformative initiative helps the firms to manage their internal knowledge network by significantly achieving sustainable business competitiveness. Given the articulation, the study states that a firm's transformation capacities foster the firm's knowledge management capabilities, thus attaining a competitive advantage (27).

In particular, TRC is the unique valuable intangible assets of the company that help it to attain sustainable CA. As such, the current study proposes the following hypothesis:

H1(b): Transformative capacity positively influences firm competitive advantage

Inventive Capacity and Competitive Advantage

Inventive capacity (INVC) is a firm's ability to generate information inside the firm by identifying a particular opportunity (23). Over the years, the notion of the firms' innovative capabilities' has come into the spotlight. In the twenty-first century, the firms' innovation capabilities' have played a dominant role in accelerating the firms' competitiveness. The innovation capabilities manage the firms' products and processes conducive to developing competitive advantage. Accordingly, the study shows that the development of the firms' innovation capacities governs the firms' operations, thereby promoting firms' competitiveness (28). Knowledge INVC facilitates a firm's learning process and business performance. Based on this statement, the research shows that a firm's innovation ability helps to improve its business performance and competitiveness (29). Moreover, the INVC plays a fundamental role in creating higher profits and competitive benefits. A firm's INVC capabilities expand its business opportunities by shaping the firm's business model (30, 31), thus establishing a superior competitive edge (6). Indeed, the literature concludes that the effective development of INVC helps an organization achieve a distinctive edge over its competitors (32). Accordingly, the current study proposes the following hypothesis:

HI(c): Inventive capacity positively influences firm competitive advantage

Supply Chain Agility and Competitive Advantage

Supply chain agility (SCA) is the company quick response to the continuously changing market trends (33). The previous literature found that SCA has appeared as an important source of competitiveness in the current period of company instability (10). In recent years, increased market volatility has caused businesses to enhance their supply chain capability to improve their CA. Hence, in this regard, increased attention is given to SCA to speed up a firm's performance and competitiveness.

In explaining this notion, the research states that a firm's SCA redesigns the firm's process by improving its business performance and competitiveness (34). Moreover, a firm's SCA magnifies the market demand and the extent to which the firm can respond to substantially satisfy its customers' needs. Accordingly, the literature states that SCA positively accelerates stakeholder demand, thus increasing the firms' performance and competitiveness (35, 36). Altogether, supply chain agility is vital to achieving a competitive advantage. In this regard, the study suggests that to sustain the knowledge economy, companies should retain their competitiveness *via* supply chain agility (37). As such, the current study proposes the following hypothesis:

H2: Supply chain agility positively influences firm competitive advantage

Absorptive Capacity and Supply Chain Agility

The past literature proposes that real CA is based on a company's potential to use existing information to produce updated items according to need or demand of customers as time passes (10). Significantly, AC improves a fir's' knowledge beyond its boundaries. AC is most relevant to updating a firm's supply chain knowledge, thus rapidly enhancing and satisfying the stakeholders' demand for critical information. Therefore, to justify this relationship, the research states that AC stimulates, transforms, and recognizes sensitive stakeholder information to improve a firm's performance and SCA (38). It is noteworthy that AC develops a significant relationship with the SCA for increasing the firms' knowledge acquisition. Indeed, absorptive capability is an effective means for driving supply chain agility. The absorptive capacity increases the firm's effectiveness, thus contributing to supply chain agility. Based on this statement, the study states that absorptive capacity improves the firms' performance and agility (39, 40). Hence, as a result, the companies should adopt AC to improve the SCA.

Accordingly, the previous literature confirms that higher AC increases organizational learning, thus facilitating SCA. Hence, based on this statement, the research states that AC improves a firm's performance and agility (40). As such, the current study proposes the following hypothesis:

H3(a): Absorptive capacity positively influences supply chain agility

Transformative Capacity and Supply Chain Agility

Past studies illustrate that the exercise of KM involves the implementation of information to current and later decision-making activities from prior decisions, experiences, or operations (41). Undoubtedly, growing KM in the supply chain has enhanced firms' agility. As a result, today, firms are profoundly incorporating TRC to improve SCA. In the knowledge economy, the novel transformative paradigms have driven the business processes to accelerate firms' innovative capabilities and SCA. Based on this statement, the research states that TRC synchronizes a firm's processes by fostering SCA (42). Indeed, the application of TRC ensures that a firm achieves SCA. Over the years, the TRCs have brought incremental improvements to firms' innovation processes by radically achieving organizational agility. This notion leads firms to embrace transformative practices to rationalize SCA. As such, the researchers state that the digital technological capacities contribute to a firm's SCA, thereby improving its performance (43, 44). As such, the current study proposes the following hypothesis:

H3(b): Transformative capacity positively influences supply chain agility

Inventive Capacity and Supply Chain Agility

Innovation is the prime determinant of a firm's supply chain operation that helps it to compete in today's business environment. Companies operating in this context have developed INVCs for accelerating supply chain activities. Undoubtedly, the changes in the business environment have led to firms improving their INVCs to meet the customers' demands, thus improving business performance and SCA (45). The previous literature found that in-house research and development has a significant impact on performance and innovation (10). A firm's innovative infrastructure provides information by allowing digital platforms to influence SCA. In particular, the profound characteristics of digital transformations leverage the firms' capabilities to enhance SCA.

With the rapid development in information and technology, the study shows that firms' innovation capacities have improved supply chain agility. The innovation capabilities develop a seamless supply chain connection, thus leveraging the firms' agility performance (46). In explaining this notion, the research states that INVCs strengthen a firm's ability to improve SCA (47). Indeed, the literature confirms that INVCs enhance SCA. In the explanation, the study shows that a firm's IC accelerates its process agility (48). Consequently, the literature concludes that a firm's INVCs and digital transformations are crucial for adapting SCA. As such, the current study proposes the following hypothesis:

H3(c): Inventive capacity positively influences supply chain agility

The Mediating Role of Supply Chain Agility

SCA has emerged as an important factor and has a significant influence on firm performance (49). The success of creating sustainable CA in supply chain management is highly dependent on knowledge and the extent to which it is effectively managed (50). Gaining AC fundamentally inspires an organization to use its knowledge resources to gain sustainable CA. A firm's knowledge capability makes the organization competitive. Moreover, absorptive capacity improves the firms' knowledge acquisition, thereby translating the firm's performance into a sustainable competitive advantage. Perhaps, to understand this concept, the study states that absorptive capacity accelerates the firms' performance, thus raising the business competitiveness (38).

To explain this notion, the research shows that a firm's knowledge capability (i.e., AC) satisfies the needs of the supply chain, thereby making this strategic resource (e.g., SCA) attain

superior CA (10). Therefore, by assessing the role of AC in fostering SCA and firms' competitiveness, it has become imperative for organizations to adopt ACs to gain a CA. To theoretically develop the argument on this perspective, the literature has concluded that CA primarily depends on a company's knowledge resources application, accelerating SCA and CA.

In particular, SCA plays a significant role in anticipating market changes and customer demand. Therefore, to survive in today's turbulent landscape, the emerging digitalization has made SCA crucial to establishing a distinctive CA. TRC holds a prominent position in KM by providing organizations with numerous strategic opportunities to achieve firm CA. In explaining this notion, the research states that a firm's TRCs synchronize the supply chain process, thereby increasing the firm's SCA and CA (51).

Further, knowledge significantly fosters organizational INVC and CA (52). As a result, numerous companies have adopted INVC to explore novel business opportunities. In the supply chain, by responding to the new possibilities, firms have embraced INVCs, fostering SCA to achieve CA (53). In particular, in today's competitive market, organizations have adopted INVC to influence the firm's SCA (47), ultimately enhancing its CA.

Significantly, today's organizations have adopted the agility for establishing dominant market competitiveness. In this regard, innovative capabilities play a critical role in achieving competitive advantage. Therefore, today, INVC are recognized as the most significant driver of SCA and CA. However, developing supply chain agility and innovativeness demands the organizations to effectively manage the innovation capacities, thus achieving a competitive advantage (54). In explaining this notion, the literature states that a firm's INVC enhances its SCA (55), substantially leading to CA. Consequently, due to the increasing significance of INVCs in the supply chain, it is suggested that management should improve their knowledge capabilities to increase the value of SCA and CA. Therefore, based on the gathered data, the current study proposes the following hypothesis:

H4(a): Supply chain agility mediates the relationship between absorptive capacity and competitive advantage

H4(b): Supply chain agility mediates the relationship between transformative capacity and competitive advantage

H4(c): Supply chain agility mediates the relationship between inventive capacity and competitive advantage

The Moderating Role of Inter Functional Integration

Inter-functional integration (INTF) is a firm's internal functional department's ability to collaborate, coordinate, and communicate information or activities among all the departments of the firm who are working toward the same goal and work jointly to achieve the task as quickly as possible (56). The better a firm's INTF, the quicker it will achieve its business goals or react immediately to clients' needs. As mentioned, SCA is the ability to respond to the new trends of the market quickly and effectively by redesigning the process and operation of the firm according to the needs of market. As such, when a firm has strong INTF, those within the firm will work together to update the internal process effectively or to respond faster than competitors at right time in the market changes by satisfying their customer or retaining their customer. In this way, the firm can gain a good position in the business by reacting to changing demands or targeting their competitors to sustain the firm's CA.

Empirical evidence exists that the units working together like this assists in improving new products and processes development (57) as well as enhancing firm performance (58). A prior study explores how interaction among functional units has an influence on work performance (59). In explaining this notion, the study states that INTF allows firms to improve their supply chain performance (60), thereby achieving a superior CA.

Today, organizations are experiencing market pressure to provide superior supply chain services, thus establishing firms' competitiveness. In this regard, the firms' functional integration has emerged as a significant construct that complements the supply chain agility and competitiveness (61).

As a result, many companies have increasingly enhanced their supply chain activities, thus attaining a competitive advantage. Understanding the impact of INTF, firms have realized the significance of using an integrated system for creating and sharing value among the supply chain network. In particular, such integration models develop a competitive supply chain approach that enables firms to achieve market competitiveness. This integrated process provides high value to firms by improving their agility, abilities, and competitiveness (62). Therefore, the use of an integrated model has become a critical strategy for fostering SCA and competitiveness. As such, the current study proposes the following hypothesis:

H5: Inter functional integration positively moderate the connection between supply chain agility and firm competitive advantage.

Figure 1 shows study theoretical framework (Independent, dependent, mediating and moderating variables).

RESEARCH METHODOLOGY

The purpose of this research study was to investigate the influence of three KM capacities (AC, TRC, and INVC) on firms' CA, the mediating role of SCA between KM capacities, and firm CA, plus the moderating role of INTF between SCA and CA. The supply chain managers of pharmaceutical firms were invited to respond with information about their firm's KM capacity at time 1 and SCA and the INTF at time 2, then firm CA at time 3, and the final sample size was 308 after data screening. Demographic characteristics of the study participants are depicted in **Table 1**, revealing 89.7% male and 10.3% female. 54.6% participants of age group 31–35; 35.5% were from 36 to 40. 90.2% of participants were master's degree holders, and 9.8% were M.Phil./Others.

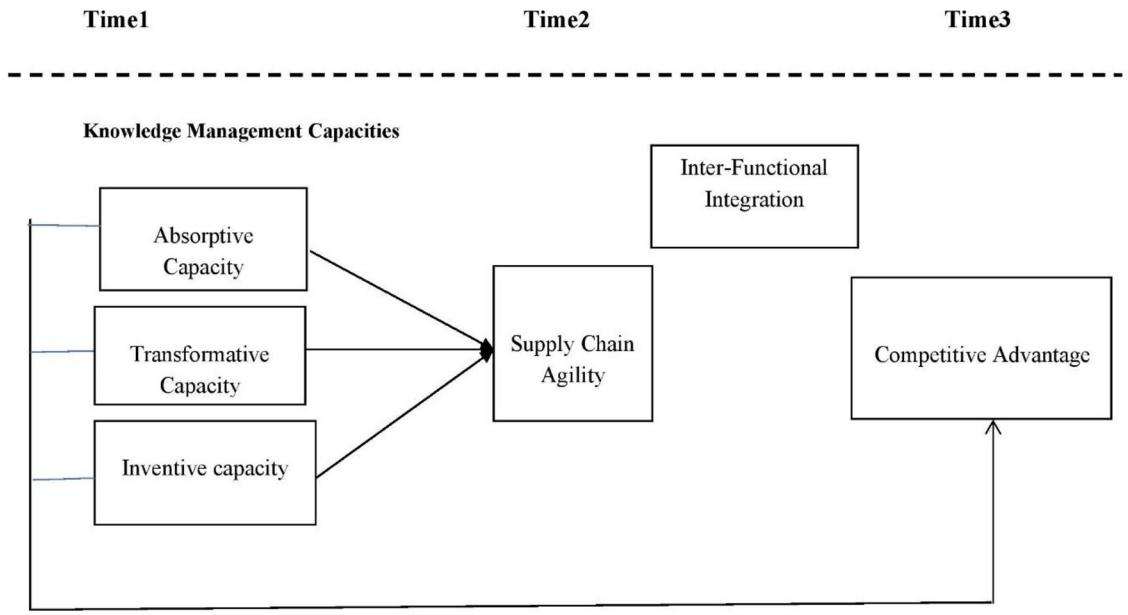


FIGURE 1 | Conceptual framework.

TABLE 1 | Demographic characteristics.

Items	(%)
Gender	
Male	89.7%
Female	10.3%
Age	
25–30	1.2%
31–35	54.6%
36–40	35.5%
41–50	6.3%
>50	2.4%
Education	
Master	90.2%
MPhil/Others	9.8%

Study Measures

Self-administrated questionnaires were developed for data collection. All the questionnaires were distributed in English. In the questionnaire, the first paragraph explained the scope and purpose of the study. Data were collected from supply chain managers of pharmaceutical firms during three different periods. The strict anonymity of the respondents regarding their responses was assured, and their participation was voluntary. The non-probability convenient sampling technique was used for questionnaire distribution. The included items were adapted from established instruments from the previous literature.

Absorptive Capacity was measured using a 13 item scale developed by Jansen et al. (63). Sample items include: "Our unit has frequent interactions with corporate headquarters to acquire new knowledge"; "Our unit regularly considers the consequences of changing market demands regarding new products and services."

Inventive Capacity was measured using a three item scale developed by Lichtenthaler and Lichtenthaler (23). Sample items include: "Ability to the importance of internally explore knowledge or generate internally new knowledge."

Transformative Capacity was measured using an eight item scale developed by Lichtenthaler and Lichtenthaler (23). Sample items include: "New opportunities to serve our customers with existing technologies are quickly understood" and "Knowledge management is functioning well in our company."

Competitive Advantage was measured using a six item scale developed by Vorhies and Morgan (64). Sample items include: "Compared with our competitors, we provide dependable delivery"; "Compared with our competitors, we quickly deliver products to the market."

The mediating variable supply chain agility was measured using a 22 item scale developed by Garver and Mentzer (65). Sample items include: "Our firm can promptly identify opportunities in its environment"; and "We always receive the information we demand from our suppliers."

The moderating variable Inter Functional Integration was measured using a 10 item scale developed by Van de Ven and Ferry (66). Sample items include: "To coordinate activities with these other departments during the past 6 months, to what extent have standard operating procedures been established?" It was measured using a five-point Likert scale ranging from "no extent" to "very great extent." "During the past 6 months, my department are involved with other departments to receive or send work and

TABLE 2 | Correlation, reliability, and validity statistics.

	ICR	CR	AVE	INF	IC	AC	SCA	CA	TC
INF	0.965	0.946	0.745	(0.863)					
IC	0.923	0.847	0.734	0.005**	(0.857)				
AC	0.905	0.899	0.538	0.032**	0.296**	(0.734)			
SCA	0.988	0.968	0.669	0.014**	0.094**	0.154**	(0.818)		
CA	0.964	0.964	0.818	0.079**	0.403**	0.460**	0.263**	(0.904)	
TC	0.810	0.933	0.778	0.094**	0.662**	0.253**	0.071**	0.408**	(0.882)

***Correlation is significant at the 0.01 level (2-tailed). INF, inter functional integration; IC, inventive capacity; TC, transformative capacity; AC, absorptive capacity; SCA, supply chain agility; CA, competitive advantage; ICR, internal consistency reliability; CR, composite reliability; AVE, average variance extracted; Values on the diagonal represent the square root of the average variance extracted (discriminant validity), while the off diagonals are correlations.*

TABLE 3 | Hypotheses testing.

Hypothesis	Relationships	Std. beta	Std. error	*T*-values	*P*-values
H1(a)	AC → CA	0.8672	0.1099	7.8940	***
H1(b)	TC → CA	0.4731	0.0918	5.1547	***
H1(c)	IC → CA	0.6784	0.0512	13.2598	***
H2	SCA → CA	0.343	0.0503	6.814	***
H3(a)	AC → SCA	0.527	0.1168	4.516	***
H3(b)	TC → SCA	0.5093	0.0912	5.5862	***
H3(c)	IC → SCA	0.6754	0.0505	13.3785	0.0000
		Std. beta	**Std. error**	**LLCI**	**ULCI**
H4(a)	AC → SCA → CA	0.1809	0.0544	0.0872	0.3004
H4(b)	TC → SCA → CA	0.1900	0.0457	0.1102	0.2902
H4(c)	IC → SCA → CA	0.6836	0.0686	0.5473	0.8153

*n = 308. ***p < 0.001; IC, inventive capacity; TC, transformative capacity; AC, absorptive capacity; SCA, supply chain agility; CA, competitive advantage; LL, lower limit; CI, confidence interval; UL, upper limit.*

to receive or send technical assistance." It was measured using a five-point Likert scale ranging from "not at all" to "very much."

Measurement Model Evaluation

Confirmatory factor analysis was used to test the data validity obtained from the Six-factor model. Initially conducted confirmatory factor analysis indicated AGFI, NFI, and CFI values were not in a suggested range (CMIN = 2,040, DF = 766, $p <$ 0.000, CMIN/DF = 2.664, CFI = 0.90; GFI = 0.767, RAMSA = 0.071). Therefore, as per the suggestion (67), error terms were connected after observing modification indices values. Hence measurement model was improved with CMIN = 1,792, DF = 764, $p <$ 0.000, CMIN/DF = 2.346, CFI = 0.940; GFI = 0.856, RAMSA3 = 0.06. In addition, all items on their corresponding latent variables were positively loaded.

RESULTS

Illustrates the correlation, reliability, and validity analysis of the study variables (**Table 2**). The table depicts the analysis values within the range that Hair et al. (67) advised. As shown competitive advantage is significantly related to inventive capacity ($r = 0.403^{**}$), transformative capacity ($r = 0.408^{**}$) and absorptive capacity ($r = 0.460^{**}$). Similarly, inter-functional integration is significantly related to competitive advantage ($r = 0.079^{**}$, $p < 0.05$) and supply chain agility ($r = 0.014^{**}$).

Hypothesis Testing

Table 3 reveals results of hypothesis H1(a), H1(b), and H1(c); H2, H3(a), H3(b), and H3(c), and H4(a), H4(b), and H4(c) (mediation analysis). Hypothesis 1 states that knowledge management capacity (absorptive, transformative and inventive) is positively related to competitive advantage with $\beta = 0.8678$, $p < 0.001$; $\beta = 0.4731$, $p < 0.001$; $\beta = 0.6784$, $p < 0.001$, respectively; moreover, Hypothesis 2 states that supply chain agility is positively related to competitive advantage with $\beta = 0.343$, $p < 0.001$. Hypothesis 3 states that knowledge management capacity (absorptive, transformative and inventive) is positively related to supply chain agility with $\beta = 0.527$, $p <$ 0.001; $\beta = 0.5093$, $p < 0.001$; $\beta = 0.6754$, $p < 0.001$, respectively. Hence Hypothesis H1(a), H1(b), H1(c), H2, H3(a), H3(b), and H3(c) are statistically proved. Mediation analysis and indirect effects were calculated using Macro Process by Hayes with Model 4. Preacher and Hayes (68, 69) suggested that if there are no opposite sign in the values of LLCI and ULCI of a relationship; mediation is said to prove. Hence based on the statistics results depicted in with no opposite signs, hypothesis H4(a), H4(b), and H4(c) is proved (**Table 3**).

TABLE 4 | Interaction and conditional effects.

Hypothesis	Interaction effects	Std. beta	Std. error	*T*-value	*P*-value
H5	Interaction SCA*INF→CA	0.2040	0.0725	2.8151	***
	Level of the moderator	**Effects**	**Boot SE**	**LLCI**	**ULCI**
Conditional effects					
	MOD−1 SD (−0.69927)	0.1896	0.0699	0.0521	0.3271
	MOD M (0.00)	0.3323	0.0531	0.2278	0.4367
	MOD +1 SD (0.69927)	0.4749	0.0767	0.3240	0.6259

*n = 308. ***p < 0.001; Inter functional integration; SCA, supply chain agility; CA, competitive advantage; LL, lower limit; CI, confidence Interval; UL, upper limit.*

In line with hypothesis 5, the interaction term of supply chain agility and inter-functional integration was significant ($\beta = 0.2040$, $p < 0.001$). Moreover, the results in **Table 4** depict that the relationship between supply chain agility and competitive advantage strengthens when inter-functional integration is high ($\beta = 0.4749$, $p < 0.001$; see **Figure 2**).

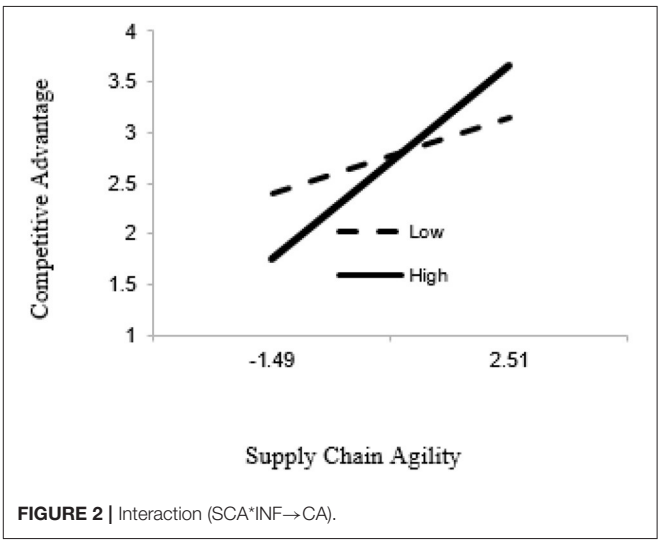


FIGURE 2 | Interaction (SCA*INF→CA).

DISCUSSION

Today's continuously changing business environment creates a big challenge for companies to retain a competitive position in challenging circumstances. Due to continuously changing market trends and customer demands, a firm needs to focus on opportunities as quickly as possible to minimize the risk of business failure or retain their customer. So, for this, valuable information plays a major role in business flourishment. Knowledge management is the firm intangible resource that has a greater impact on firm performance. To identify new opportunities, a firm needs valuable information that helps improve internal processes and operations quickly according to customers' demands. From valuable information, a firm can identify opportunities quickly and minimize the risk of business failure. The valuable information will lead to making better decisions and making changes quickly at the right time. In short, the current study investigates first: the relationship between knowledge management capacities (absorptive, transformative, and inventive) and competitive advantage; second: supply chain agility mediates the relationship between knowledge management capacities and sustainable competitive advantage; third: the moderating role of inter-functional integration between supply chain agility and competitive advantage.

Significantly, knowledge is an intangible asset that enables organizations to achieve superior competitive advantage. In particular, knowledge dominance enhances the firms' capabilities, thereby making the organizations perform to their fullest. It provides an opportunity for the firms to relish the benefit of knowledge management by gaining market-based superiority. However, knowledge management has become a vital tool for fostering business competitiveness. Given the illustration, the study states that today's organizations are increasingly adopting knowledge management practices, thus achieving a competitive advantage (70). Accordingly, due to the increasing significance of the knowledge resource, the organizations are massively embracing novel capabilities, fostering the firms' competitiveness. In this regard, the study shows that absorptive capacity has become a vital construct stimulating the firms' competitiveness (71). Additionally, the research indicates that transformative capacities and innovation capacities also increase the firms' competitiveness. Indeed, our results have supported the prior research findings, thus recording positive results.

Moreover, in today's knowledge economy, supply chain agility plays a role in coping with the increasing market pressures. In explaining this notion, the study states that supply chain agility significantly improves the firms' business performance, ultimately achieving competitive advantage (72). In addition to this, others researchers showed that the knowledge capacities (i.e., AC, TC, and IC) have also accelerated supply chain agility. Similarly, the study also confirmed the mediating role of the supply chain agility to support the previous studies that state that knowledge capabilities (e.g., AC) accelerate the supply chain agility, ultimately gaining competitive advantage (38). In particular, achieving supply chain competitiveness has become a dominant priority of today's firms. In achieving this goal, the study indicates that an organization's inter-functional

integration improves the supply chain agility, ultimately the firm's competitiveness (62).

Macro Process suggested by Hayes was used to statistically check the proposed hypotheses H1, H2, H3, H4, and H5 (mediation and moderation analysis). The results revealed that knowledge management capacities (absorptive, transformative, and inventive) are positively and significantly associated with supply chain agility ($\beta = 0.527^{***}$; $\beta = 0.5093^{***}$; $\beta = 0.6754^{***}$) and competitive advantage ($\beta = 0.8672^{***}$; $\beta = 0.4731^{***}$; $\beta = 0.6784^{***}$). Supply chain agility is positively associated with competitive advantage ($\beta = 0.343^{***}$). Henceforth hypotheses H1, H2, and H3 were approved.

Indirect effects results reveal that supply chain agility fully mediates the relationship between knowledge management capacities (absorptive, transformative, and inventive) and competitive advantage. Whereas, inter-functional integration moderates the relationship between supply chain agility and competitive advantage, the relationship strengthens when inter-functional integration is high.

CONCLUSION

Over the past several years, knowledge management has been promoted as an important intangible resource and a necessary factor for an organization to survive in fast-growing business competition; it's vital to achieve competitiveness over rivals and strength in the business circle. Knowledge is an important, valuable asset and has become a serious concern for organizations.

In recent years the mission and vision of business sectors have created novel knowledge and information. The present research is performed to identify the significance of knowledge management capacities and their influence on the competitiveness of the enterprise and the SCA of the firm. Knowledge management capacities (Absorptive, Transformative, and Inventive) have a major influence on the competitive advantage of the firm and supply chain agility. Knowledge management capacities help the firm identify opportunities by acquiring knowledge from an external or internal source or retaining information within a firm. Thus, the more firm has better manage their knowledge management capacities, the more it flourished the work performance internally and will have a significant effect on (SCA).

Knowledge management capacities (KMC) have a significant role in speeding up the supply chain agility to remain competitive in the business circle and target competitors to achieve a competitive position. Thus, the result demonstrates that inter-functional integration has a beneficial impact on (SCA) or has a beneficial influence on the enterprise's competitive position. Inter-functional integration connects employees by sharing and communicating information to accomplish the task quickly and effectively. Inter-functional integration enables the firm to respond quickly to customer need and changing trends by sharing valuable information across the functional units and working together to perform the task effectively or achieve the firm goal.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

FUNDING

This research was supported by the University Research Innovation Fund of Science and Technology Development Center of the Ministry of Education of China (2020ITA05022), the Natural Science Foundation of Hubei Province (2021CFB316), the Preliminary Support Project of Hubei Social Science Foundation (21ZD137), and the Hundreds of Schools Unite with Hundreds of Counties-University Serving Rural Revitalization Science and Technology Support Action Plan (BXLBX0847).

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frontiers | Frontiers in Public Health

ORIGINAL RESEARCH
published: 13 July 2022
doi: 10.3389/fpubh.2022.944090

Public-Public Collaboration for Food Safety Risk Management: Essence, Modes, and Identification of Key Influencing Factors Using DANP

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Objective: Food safety risk management is an important cross-boundary issue from both theoretical and practical standpoints. Because food safety has the social attributes of public goods, public-public collaboration can be considered a particularly important mode of cross-boundary governance. The study aims to provide a theoretical basis for the Chinese government to promote public-public collaboration for food safety risk management by identifying key factors.

Methods: Based on a review of literature across diverse fields, such as political science, sociology, and new public governance, this study discusses the essence, modes, and dilemma of public-public collaboration for food safety risk management using practical explorations in various countries as the main thread and taking into account the actual situation in China. Moreover, this study quantitatively analyzes the relationships between the dimensions and factors affecting public-public collaboration and identifies key dimensions and factors using the Decision-making Trial and Evaluation Laboratory-based Analytic Network Process (DANP).

Results: Among the 20 factors in the calculation results of DANP, Lawmaking has the highest value of (f_i+e_i) (7.022) and ranks sixth in terms of influence weight. The (f_i+e_i)value of Professionalism (6.993) ranks second and its influence weight ranks fourth. The ($f_i + e_i$) value of Administrative enforcement (6.722) ranks fifth, and its influence weight ranks seventh. The ($f_i + e_i$) value of Improvement of the social environment (6.699) ranks sixth, and its influence weight ranks fifth. The ($f_i + e_i$) value of Legal authorization (6.614) ranks seventh, and its influence weight ranks tenth. Data analysis indicated that these are the five key factors affecting the governance capacity in public-public collaboration for food safety risk management.

Conclusion: The legal basis is the most important dimension affecting public-public collaboration. Legislation-based governance, administrative law enforcement–based governance, and social environment improvement–based governance in the behavior and capabilities dimension, professionalism in the basic characteristics dimension, and laws and regulations in the legal basis dimension are the five key factors.

Keywords: food safety risk, cross-boundary governance, public-public collaboration, DANP, key factor

OPEN ACCESS

Edited by:
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Chongqing University of Posts and Telecommunications, China

Reviewed by:
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Specialty section:
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

Received: *14 May 2022*
Accepted: *20 June 2022*
Published: *13 July 2022*

Citation:
Zhang L, Qin K, Li Y and Wu L (2022) Public-Public Collaboration for Food Safety Risk Management: Essence, Modes, and Identification of Key Influencing Factors Using DANP. Front. Public Health 10:944090. doi: 10.3389/fpubh.2022.944090

INTRODUCTION

Since the global outbreak of COVID-19, food safety risk management has become more complex (1), and cross-boundary governance, including public-public, public-private, multiagent, interregional, and even cross-border collaboration, has become increasingly prominent. Because food safety has the social attributes of public goods, public-public collaboration is applicable as a particularly important mode of cross-boundary governance. However, most countries have not effectively addressed the problem of fragmentation among government regulators (2). Numerous studies have examined the main factors affecting public-public collaboration and yielded important findings. However, these findings are dispersed across different fields in the literature. There are few systematic studies on this topic.

Accordingly, this study summarizes relevant literature from diverse fields such as political science, sociology, and new public governance. On this basis, using practical explorations of public-public collaboration for food safety risk management in various countries as the main thread, and taking into account the actual situation in China, quantitative research is conducted using DANP to systematically examine the relationship between the dimensions and factors affecting public-public collaboration on food safety risk management and identify key dimensions and factors. This study presents systematic and comprehensive research results and provides guidance for policy-making for promoting public-public collaboration in China.

ESSENCE AND MODES OF PUBLIC-PUBLIC COLLABORATION FOR FOOD SAFETY RISK MANAGEMENT

Food safety risks exist in all stages of human social development, and managing food safety risks has always been a major public issue facing all countries throughout the world (3). However, the disadvantages of Western governments playing the role of "super nanny" in public management have become increasingly apparent since the 1960s. The contradictions in the management of public affairs, such as employment, social security, public security, environmental protection, food safety, and maintaining fair market competition, have become increasingly prominent, making it difficult for governments to effectively manage major public issues (4). As a result, the New Public Management reform occurred, which started in the UK, then took place in the US, subsequently extended to other western developed countries, and finally spread to many developing countries (5). However, problems such as inequality of politics and resources, fragmentation of power, and cleavability of services became more prominent in Western countries after nearly 20 years of New Public Management reform (6). Hence, Western countries experienced a second reform known as the post- New Public Management in the late 1990s. The two reforms are considered landmark events of public management reform by Western governments. It has been recognized that public management is an important cross-boundary theoretical and practical issue. The concept and theory of cross-boundary governance have thus been gradually developed and applied in practice, which led governments to effectively promote the development of public-public collaboration for food safety risk management (7).

Essence of Public-Public Collaboration

Food safety is characterized by inseparability of utility, non-rivalry of consumption, and non-exclusivity of benefits (8). Moreover, food safety risks travel along the supply chain. Due to the butterfly effect, the possible superposition and resonance of risks during such travel may trigger food safety incidents (9). Food safety incidents not only harm public health, but also affect the development of the food industry and even cause social unrest (10). Therefore, all countries face the challenge of preventing food safety risks (11). Many countries' governments have devoted significant efforts and implemented a series of measures to address this issue (12). However, as the New Public Management and post-New Public Management reforms proceeded, it was realized that, similar to other public affairs, food safety risk management is a task that requires multiagent collaboration (13) to break through the inherent barriers between public sectors in traditional public management, resolve the problems of blurred boundaries, overlap, and fragmentation, and eliminate government and market failures caused by the blurred functional boundaries and fragmentation among the various actors (14). This is the essence of public-public collaboration for food safety risk management.

Main Modes of Public-Public Collaboration

Since the 1990s, the concept of cross-boundary governance in the public governance theory of Western countries has been extended to apply to food safety risk management. A variety of public governance theories, such as networked governance, multilevel governance, collaborative governance, and whole of government (15–19), have become important theoretical paradigms to guide research on cross-boundary governance for food safety risk management. Based on the actors involved, Toppinen and Korhonen (20), Bunthof et al. (21), Yu and Xiao (22), Kim et al. (23), and Diehlmann et al. (24) defined four basic types of cross-boundary governance of public affairs, including food safety risk management: public-public, public-private, interregional, and multiagent. Regardless of type, however, the essence of cross-boundary governance is that different actors at the same or different levels achieve coordinated governance of major public affairs for the sake of the public interest by breaking through traditional boundaries (25).

As a commodity, food has common attributes of commodities. However, it also has the social attributes of public goods because food safety is related to the health of citizens (26). Therefore, public-public collaboration is the most important mode of cross-boundary governance in this case. Similar to the governance of other public affairs, there are two modes of public-public collaboration for food safety risk management: horizontal collaboration, which crosses the boundaries of government agencies at the same level (27), and vertical collaboration, which crosses the boundaries of government agencies at different levels

(25). All other modes are a combination or extension of these two modes.

From a global perspective, although different countries have different structures of government agencies, food safety risk management always involves not only specific industry regulators, such as those governing the agriculture, forestry, fishery, and processing industries, but also public service agencies, such as those overseeing market regulation, health, quality standards, food consumption, and imports and exports. Therefore, risk prevention requires government agencies at the same level to cross organizational boundaries to overcome fragmented governance (28), as well as building a clear governance authority and responsibility system across government agencies from the central to the local level to give full play to their respective advantages, share information, effectively interact, and ultimately achieve coordinated and unified efficient governance (29).

Dilemma of Public-Public Collaboration

For a long time, the governments of many countries, especially those of Western countries, have conducted extensive practical explorations regarding how to enact food safety regulators and achieve effective cross-boundary governance among regulators. The US federal government's food safety regulator was established in 1906. At present, there are as many as 15 regulators at the US federal level that perform different functions. Although public-public collaboration has been continuously optimized in long-term development, the problems of fragmentation, inconsistency, and overlap of regulation among government agencies have not been well-resolved, which has affected the overall governance capacity (30).

In fact, these problems are common in Western countries, although to varying degrees (31). In response, there have been calls in Western countries over the last 20 years to merge regulators to eliminate gaps between them. In the US, it has been suggested that the federal government should merge multiple regulators into a single one, which is believed to be the most effective way to address the fragmentation of regulation among various agencies (32). However, the merger of regulators involves a series of complex issues, such as legal revision, resource reorganization, and system reconstruction. Moreover, the food supply chain's complexity, which is a result of factors such as a long industrial chain, low ignition point, and many contacts, the cross-boundary governance among regulators may be more effective than a simple merger (33). Regrettably, however, Western countries have yet to resolve the fragmentation among regulators, and cross-boundary governance still faces many intractable problems (2).

The same is true in China. Over the last 40 years of reform and opening up, the Chinese government has carried out eight different reforms of food safety regulators, with one reform occurring approximately every 5 years. Up to now, the regulatory structure has been based on the State Administration for Market Regulation, Ministry of Agriculture and Rural Affairs, General Administration of Customs, and National Health Commission, supplemented by more than 10 other participating agencies, such as Ministry of Commerce, State Administration of Grain, National Forestry and Grassland Administration, and Ministry of Education. However, a clear fragmentation of regulation still exists among these agencies, which is the inherent institutional reason for the continuous emergence of food safety problems in China, and thus requires further reforms.

DIMENSIONS AND FACTORS AFFECTING PUBLIC-PUBLIC COLLABORATION FOR FOOD SAFETY RISK MANAGEMENT

A comprehensive review of existing literature on cross-boundary governance suggested that the major factors affecting the governance capacity in public-public collaboration for food safety risk management can be examined in terms of five dimensions: basic characteristics, legal basis, functions, behavior and capabilities, and infrastructure and culture of government agencies.

Basic Characteristics of Government Agencies and Public-Public Collaboration

A country's government, consisting of different levels of legislative, executive, and judicial institutions, is the manifestation of the state's authority (34). The literature review revealed that government agencies exhibit four basic characteristic factors: legal person, power level, subordination, and professionalism (35). These are important dimensions affecting public-public collaboration. Ardoin et al. (36) suggested that legal person characteristics give government agencies the ability to perform civil responsibilities for public governance. The power-level characteristics refer to the administrative levels of agencies in the national governance system. The higher the power level, the higher the authority of governance, the stronger the ability to allocate resources and coordinate other agencies, and the greater the impact on public-public collaboration (37). For example, the US Federal Food and Drug Administration (FDA) is a specialized government agency that relies on the central government's authority to coordinate local governments to jointly ensure food safety (38).

The subordination characteristics refers to whether the agencies are in a vertical relationship of leading or being led by other agencies in the governance system, which affects the public-public collaboration. In the Chinese government's food safety risk management system, customs agencies responsible for import and export food safety regulations are in a typical vertical relationship. Local customs agencies are directly led by higher-level customs agencies and only have a synergistic relationship with local market regulators at the same level. In contrast, there is no subordination between the US federal and local FDAs, and local FDAs are independent agencies (39).

Professionalism refers to an agency's professional competence to manage food safety risks. Liu (31) investigated food safety regulators in 22 countries and found that despite their different configurations, they all met relevant professional requirements, such as having antitrust and quality control standards, and requiring quarantine of plants and animals. Woldesenbet (35) found that professional competence is an important

factor affecting public-public collaboration. For example, the foundation of the US's global reputation for food safety lies in its long-term focus on professional capacity building of the FDAs at all levels.

Legal Basis of Government Agencies and Public-Public Collaboration

Legal liability is a distinctive development that differentiates modern societies from traditional ones. Legal authorization acts as the basic guarantee for public-public collaboration for food safety risk management (40, 41). The 15 agencies set up by the US federal government related to food safety regulation are authorized by at least 30 laws (42). Different legal bases have specific applicability and binding force. Laws passed by the legislature are mandatory, whereas normative documents issued by the government are less binding (43). In China, central and local regulators usually implement non-legislative documents with a certain binding force within the scope of legal authorization, i.e., normative documents, to regulate important food safety matters.

Meanwhile, informal rules, including voluntary initiatives, although not mandatory, have become an important basis for mutual compliance among government agencies and promoting public-public collaboration due to the ambiguity of the law (44). Robinson (45) reported that 71 inter-agency agreements on food safety regulation have been signed among United States Department of Agriculture (USDA), FDA, Environmental Protection Agency (EPA), and the National Marine Fisheries Service (NMFS). Regarding some food safety regulation issues, such as food safety risk assessment and foodborne disease prevention, the US FDA, Food Safety and Inspection Service (FSIS), Centers for Disease Control and Prevention (CDC), and National Institutes of Health (NIH) have formed PulseNet, an inter-agency network to monitor, detect, and investigate outbreaks of foodborne disease outbreaks (46).

Path dependence refers to the fact that once a rule is formed in a system, it is often difficult to change the actual and potential impact of that rule. Fortwengel and Keller (47) found that path dependence exists for rules in public-public collaboration. Chen et al. (48) believed that the segmentation of regulations among agencies as long implemented in China is a typical manifestation of path dependence. Merrill and Francer (49) also suggested that path dependence exists in the US government's food safety regulation system, and that the historically formed division of powers among government agencies is particularly stubborn.

Functions of Government Agencies and Public-Public Collaboration

Generally speaking, from the vertical perspective, central regulators deal with the most important administrative affairs in food safety risk management on behalf of the state and occupy a dominant position, whereas local regulators are in a subordinate position. From the horizontal perspective, the positions, functions, and responsibilities of various agencies at the same level in the food safety co-governance system do not match. For example, since the reform and opening up in 1978, China has undergone eight nationwide institutional reforms to develop a regulatory system based on the market regulation, agriculture and rural affairs, customs, and health agencies, supplemented by other participating agencies. Among them, the agriculture and rural affairs, health, and customs agencies are responsible for regulating the production of agricultural products prior to entering the market, development of food safety standards, and import and export food safety regulation, respectively. They are all single-function dominant agencies in this system.

The market regulation agency undertakes almost all functions other than those undertaken by the agriculture and rural affairs, health, and customs agencies, such as those concerning food production and processing, storage and circulation, and consumption, and thus is a comprehensive dominant agency. Other participating agencies, such as forestry, grain, commerce, and education agencies, are indirectly involved in governance in a specialized manner (50), and are thus all auxiliary agencies. According to resource scarcity theory, government agencies with different functions hold and accumulate different resources and play different roles in the governance system (51).

Compared with the situation in China, Western countries not only have different modes of multiagency food safety governance, but the functions, responsibilities, and authority of the relevant agencies are also different. For example, the USDA's authority is greater than that of the FDA (52). The same is true in the European Union (EU). Although there are multiple agencies for food safety management in EU countries, the European Food Safety Authority plays a dominant role (53).

Behavior and Capabilities of Government Agencies and Public-Public Collaboration

Lawmaking, administrative enforcement, judicial enforcement, and improvement of the social environment are the main paths available for legislative, executive, and judicial agencies to achieve public-public collaboration for food safety risk management. However, the behavior of government agencies is determined by their legal authorization, but their governance capabilities in public-public collaboration inherently depend on their own capabilities (54). Boatemaa et al. (55) found that fragmentation of a legislature's legislative procedures from the administration's enforcement procedures restricted the effect of public-public collaboration. The research of Simon (56) on China's legal framework indicated that legislation should fully consider organically integrating the governance functions of legislative, administrative, and judicial agencies, which could help promote public-public collaboration.

Gazley (57) suggested that the legislature's legislative capacity affects public-public collaboration. Winders (58) argued that the effect of public-public collaboration depends on the organic combination and integration of the capabilities of participating agencies. In addition, based on the practice of many countries, the governance capacity for food safety risk management also depends on the improvement of the entire social environment, requiring not only the dominant agencies to perform their functions, but also the joint efforts of auxiliary agencies (59).

Infrastructure and Culture of Government Agencies and Public-Public Collaboration

The governance capacity in public-public collaboration for food safety risk management also depends on the collaborative relationships among the government agencies, especially their ability to share governance resources and infrastructure conditions (60). If the chains of power, responsibility, and information between government agencies are integrated, information can be obtained, transmitted, and shared effectively, which contributes to public-public collaboration (61). Government agencies not only require information sharing, but also need to widely apply new technologies, such as information technology, which has become an important means of public-public collaboration in modern society (62).

Cultural factors also affect the implementation efficiency of formal or informal rules among government agencies (63). Reduced bureaucracy and an institutional culture with incentives or accountability will stimulate the internal motivation of agencies to participate in public-public collaboration (64). The higher the social concern about public affairs, the easier it is to generate external environmental pressure on public-public collaboration. With the continuous development of biotechnology, the deterioration of the ecological environment, and the continuous improvement of living standards and public scientific literacy, food safety will always be a public matter of high social concern, providing such a continuous external driving force for public-public collaboration (65).

TABLE 1 | A set of dimensions and factors that affect public-public collaboration for food safety risk management is defined.

Dimensions	Factors
Basic characteristics of government agencies (D_1)	Legal person (d_1)
	Power level (d_2)
	Subordination (d_3)
	Professionalism (d_4)
Legal basis of government agencies (D_2)	Legal authorization (d_5)
	Normative documents (d_6)
	Informal rules (d_7)
	Path dependence (d_8)
Functions of government agencies (D_3)	Comprehensive dominant agency (d_9)
	Single-Function dominant agency (d_{10})
	Auxiliary agency (d_{11})
Behavior and capabilities of government agencies (D_4)	Administrative enforcement (d_{12})
	Judicial enforcement (d_{13})
	Lawmaking (d_{14})
	Improvement of the social environment (d_{15})
Infrastructure and culture of government agencies (D_5)	Information sharing (d_{16})
	Information technology (d_{17})
	Sectoral interdependence (d_{18})
	Institutional culture (d_{19})
	Social concern (d_{20})

IDENTIFICATION OF KEY DIMENSIONS AND FACTORS AFFECTING PUBLIC-PUBLIC COLLABORATION

Based on the above literature and the reality of China, a set of dimensions and factors that affect public-public collaboration for food safety risk management is defined as shown in **Table 1**.

Methodology

Table 1 lists the five dimensions and 20 factors identified as affecting public-public collaboration for food safety risk management in the global context. These dimensions and factors are not independent, but interweave, influence, and interact with each other and thus constitute a complex system. Identifying the key dimensions and factors and determining how and to what degree they influence each other will undoubtedly be of great significance to explore ways to improve the governance capacity in public-public collaboration.

Decision-making Trial and Evaluation Laboratory (DEMATEL) is considered an effective method for determining the mutual influence of causal factor chains in complex systems (66), and it is usually used in conjunction with expert systems. The Analytic Network Process (ANP) was proposed by Saaty and Saaty (67) on the basis of Analytic Hierarchy Process (AHP), and is a method to determine the weight of indicators using the influence relationships between them (68). DANP is the combination of DEMATEL and ANP. It integrates the advantages of these two methods and can obtain the optimal solution of the complex relationship between multiple dimensions and factors in a complex system through computational science (69, 70). Therefore, DANP is used in the present study.

Identifying the Influence Relationships Between Dimensions and Factors

The process used to identify the key dimensions and factors that affect public-public collaboration for food safety risk management using DEMATEL is as follows:

Step 1: Identify the dimensions and factors that affect the system. Based on the literature presented in **Table 1**, D_1, D_2, D_3, D_4, and D_5 are used to represent the five dimensions of government agencies participating in public-public collaboration for food safety risk management, i.e., basic characteristics, legal basis, functions, behavior and capabilities, and infrastructure and culture. Then, d_1, d_2, d_3, and d_4 represent the four characteristic factors of D_1, and d_5, d_6, d_7, d_8,..., d_{16}, d_{17}, d_{18}, d_{19}, and d_{20} are used to represent the characteristic factors of the dimensions D_2, D_3, D_4, and D_5, respectively.

Step 2: Investigate the relationship between factors. Using the expert opinion method, 19 experts, including 5 government officials in the market regulation system, 7 researchers from universities and research institutions, 2 experts of industry associations and 5 senior executives of food production enterprises, were invited to form an expert group. The pairwise relationships between the factors were scored according to the corresponding integer values in **Table 2** to determine the importance of each factor in the system. The initial direct relation

TABLE 2 | Conversion relationship between linguistic variables and integer values.

Linguistic variables	Integer values
No influence	0
Very low influence	1
Low influence	2
High influence	3
Very high influence	4

Refer to Hsu et al. (71) and Lu et al. (72) for the design of linguistic variables and their corresponding integer values in the table.

matrix $A = [d_{ij}]_{20\times 20}$ between factors was determined by regression estimation.

$$A = \begin{pmatrix} d_{11} & \cdots & d_{1\,20} \\ \vdots & \ddots & \vdots \\ d_{20\,1} & \cdots & d_{20\,20} \end{pmatrix} \tag{1}$$

where d_{ij} is the direct influence relationship between two factors, representing the direct influence of factor i on factor j (i and j = 1, 2, 3,...,20); for example, d_{12} indicates the direct influence of d_1 on d_2. To examine the mutual influence of two factors, if $i = j$, let $x_{ij} = 0$, indicating that the influence of each factor on itself is 0; that is, there is no influence. Hence, all elements on the main diagonal of the initial direct relation matrix A are recorded as 0.

Step 3: Calculate the normalized direct influence coefficient and normalized influence matrix. The normalized direct relation matrix G ($G = [g_{ij}]_{20\times 20}$) is expressed by equation (2). The normalized direct influence coefficient g_{ij} in equation (3) represents the influence of factor i on factor j.

$$G = g_{ij} \times A \tag{2}$$

$$g_{ij} = \min\left\{ \frac{1}{\max\limits_{1\le i\le 20}\sum_{j=1}^{20} d_{ij}}, \frac{1}{\max\limits_{1\le j\le 20}\sum_{i=1}^{20} d_{ij}} \right\} \tag{3}$$

Step 4: Calculate the total relation matrix T between factors. $T = [t_{ij}]_{20\times 20}$ can be calculated by $T = G + G^2 + G^3 + \ldots G^h = G\left(I + G + G^2 + \ldots G^{h-1}\right)\left[(I-G)(I-G)^{-1}\right] = G(I-G^h)(I-G)^{-1}$where I is the identity matrix, T_{ij} represents the direct and indirect influences of factor i on factor j, and $(I-G)(I-G)^{-1} = I$. Therefore, when $h\to\infty$, $D^h = [0]_{n\times n}$, the total relation matrix T can be expressed by equation (4):

$$T = G(I-G)^{-1} \tag{4}$$

Step 5: Calculate the influences given and received by each factor. Compute the row and column sums of matrix T to obtain the influences given and received by the corresponding factor, respectively. The following equations are used:

$$f_i = \sum_{j=1}^{20} t_{ij} \tag{5}$$

$$e_i = \sum_{j=1}^{20} t_{ji} \tag{6}$$

where f_i is the influence given by factor i, and e_i is the influence received by factor i.

Step 6: Calculate the centrality and causality of each factor. Centrality is obtained by adding the influences given and received by a system factor, which indicates a factor's position in the system as well as its effect size. The greater the centrality, the greater the factor's effect on public-public collaboration for food safety risk management. Causality is obtained by subtracting the influence given by the factor from that received by it. A positive causality indicates that the factor is a cause factor in the system, whereas a negative one indicates that the factor is an effect factor. The following equations are used:

$$m_i = f_i + e_i \tag{7}$$

$$n_i = f_i - e_i \tag{8}$$

where m_i is centrality, and n_i is causality.

Based on the scores given by the expert group for the importance of each factor, the initial direct relation matrix A shown in **Table 3** is obtained according to the calculation method in Step 2.

The initial direct relation matrix was normalized using equation (3) according to Steps 3 and 4, and then limits were computed using MATLAB according to equation (4) to obtain the total relation matrix T of different influencing factors. The Influence given and received by each factor affecting public-public collaboration for food safety risk management, denoted by f_i and e_i, respectively, were calculated using equations (5, 6) according to Step 5. On this basis, the data set of ($f_i - e_i$, $f_i + e_i$) was calculated using equations (7, 8) according to Step 6, and the results of DEMATEL in **Table 4** were obtained.

Here, ($f_i - e_i$)is the difference between the influences given by factor i to other factors and those received by it from other factors, reflecting the degree of influence of factor i on other factors in the system. For instance, (f_i+e_i) is the sum of influences given and received by factor i; $f_i - e_i > 0$ indicates that factor i has an influence on other factors in the system; whereas $f_i - e_i < 0$ indicates that factor i is influenced by other factors in the system.

Calculating the Influence Weights of Dimensions and Factors

The weights of the influences between dimensions and factors were calculated using DANP. The steps are as follows:

Step 1: Build an unweighted matrix. The total relation matrices based on dimensions and factors are represented by $T_d = [t_{ij}^D]_{m\times m}$ and $T_c = [t_{ij}]_{n\times n}$, respectively. T_c is expressed by equation (9):

TABLE 3 | Initial direct relation matrix A between different influencing factors.

Factors	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}
d_1	0.000	1.000	0.636	2.273	2.000	2.000	2.000	1.455	0.727	0.636
d_2	1.636	0.000	1.455	2.182	2.091	2.091	1.455	1.545	1.818	1.273
d_3	1.636	0.818	0.000	1.545	1.909	1.818	1.091	1.455	1.818	1.364
d_4	1.909	0.727	0.636	0.000	1.636	1.818	1.909	2.182	1.091	0.909
d_5	2.091	1.455	1.182	2.182	0.000	2.182	1.727	2.455	1.909	1.909
d_6	1.636	1.182	1.000	2.091	1.182	0.000	1.091	1.909	1.091	1.000
d_7	1.000	0.636	0.273	1.909	0.727	0.727	0.000	1.364	0.636	0.636
d_8	0.909	0.273	0.545	1.909	1.364	1.273	1.273	0.000	1.000	0.909
d_9	1.455	1.000	1.545	2.182	1.182	1.273	1.364	1.636	0.000	0.727
d_{10}	1.364	0.727	0.909	1.909	1.182	1.091	1.182	1.727	0.818	0.000
d_{11}	0.727	0.727	1.000	1.364	0.818	0.636	1.182	1.182	0.455	0.273
d_{12}	1.818	0.909	0.636	2.000	2.091	1.909	1.455	1.818	1.273	1.182
d_{13}	1.545	0.727	0.545	1.909	2.182	2.091	1.364	1.364	1.000	0.909
d_{14}	1.364	1.000	0.545	2.091	2.364	2.364	1.273	1.636	1.364	1.182
d_{15}	1.091	0.818	0.545	1.727	1.455	1.818	1.909	1.091	1.091	0.909
d_{16}	1.455	0.909	1.000	2.364	0.818	1.091	1.364	1.273	1.455	1.091
d_{17}	1.273	0.545	0.545	1.818	0.909	1.000	1.364	1.455	1.273	1.000
d_{18}	1.636	0.636	1.000	1.909	0.909	1.000	1.364	1.727	1.455	0.818
d_{19}	1.455	0.636	0.818	2.364	0.909	1.000	1.636	1.273	1.091	0.818
d_{20}	1.455	0.727	0.545	2.182	1.909	2.000	1.818	1.364	1.182	1.000

Factors	d_{11}	d_{12}	d_{13}	d_{14}	d_{15}	d_{16}	d_{17}	d_{18}	d_{19}	d_{20}
d_1	0.364	2.455	1.818	1.909	1.636	2.545	1.818	2.000	2.545	1.727
d_2	1.182	1.818	1.545	1.636	1.636	2.545	2.000	2.000	1.818	1.727
d_3	1.455	2.182	1.818	1.909	1.455	2.000	1.818	1.818	1.545	1.364
d_4	0.818	2.000	2.000	2.091	2.182	2.727	2.273	1.909	2.727	2.364
d_5	1.545	2.818	3.182	3.273	2.818	2.273	2.273	1.818	1.636	1.727
d_6	0.818	2.182	2.182	2.636	2.273	1.818	1.727	1.455	1.909	1.545
d_7	0.545	0.818	0.909	1.273	1.727	1.364	1.182	1.091	1.727	1.818
d_8	0.727	1.818	1.636	2.000	1.909	1.727	1.909	2.000	1.909	1.545
d_9	0.636	2.000	1.818	1.909	2.182	3.000	2.636	2.727	2.000	2.182
d_{10}	0.545	1.818	1.545	1.545	1.455	1.909	1.818	1.727	1.636	1.636
d_{11}	0.000	1.273	1.000	1.091	1.000	1.364	1.455	1.545	1.364	1.727
d_{12}	0.909	0.000	1.818	2.636	2.182	1.909	2.273	1.727	1.636	1.818
d_{13}	0.727	1.727	0.000	2.636	1.909	1.727	2.000	1.545	1.545	1.636
d_{14}	0.909	2.182	2.273	0.000	2.000	1.727	2.091	1.727	1.727	1.727
d_{15}	0.727	1.636	1.727	2.182	0.000	1.636	2.091	1.818	2.000	2.636
d_{16}	0.818	2.182	2.364	2.182	2.364	0.000	2.818	3.091	2.364	2.000
d_{17}	0.727	2.273	2.273	2.364	2.273	3.182	0.000	2.545	2.364	2.091
d_{18}	0.909	1.455	1.636	1.455	1.545	2.455	2.364	0.000	2.182	1.182
d_{19}	0.636	1.636	1.909	1.909	2.545	1.818	1.727	2.000	0.000	1.909
d_{20}	0.818	2.364	2.091	2.273	3.000	1.636	2.273	1.636	1.909	0.000

TABLE 4 | Results of DEMATEL.

Dimensions	f_i	e_i	$f_i - e_i$	$f_i + e_i$	Factors	f_i	e_i	$f_i - e_i$	$f_i + e_i$
D_1	1.265	1.111	0.154	2.376	d_1	3.134	2.730	0.404	5.864
					d_2	3.316	1.546	1.770	4.862
					d_3	3.049	1.424	1.625	4.473
					d_4	3.299	3.694	−0.395	6.993
D_2	1.205	1.227	−0.022	2.432	d_5	3.892	2.722	1.170	6.614
					d_6	3.039	2.906	0.133	5.945
					d_7	2.038	2.811	−0.773	4.849
					d_8	2.642	2.921	−0.279	5.563
D_3	1.185	1.021	0.164	2.206	d_9	3.295	2.239	1.056	5.534
					d_{10}	2.640	1.870	0.770	4.510
					d_{11}	2.005	1.537	0.468	3.542
D_4	1.182	1.348	−0.166	2.530	d_{12}	3.171	3.551	−0.380	6.722
					d_{13}	2.924	3.561	−0.637	6.485
					d_{14}	3.145	3.877	−0.732	7.022
					d_{15}	2.853	3.846	−0.993	6.699
D_5	1.171	1.301	−0.130	2.472	d_{16}	3.209	3.764	−0.555	6.973
					d_{17}	3.058	3.788	−0.730	6.846
					d_{18}	2.720	3.531	−0.811	6.251
					d_{19}	2.767	3.635	−0.868	6.402
					d_{20}	3.166	3.409	−0.243	6.575

$$T_c = \begin{array}{c} \\ D_1 \\ \\ \\ \\ D_i \\ \\ \\ \\ D_n \end{array} \begin{array}{c} \begin{array}{cccccc} & D_1 & \cdots & D_j & \cdots & D_n \\ & c_{11}\cdots c_{1m_1} & \cdots & c_{j1}\cdots c_{jm_j} & \cdots & c_{n1}\cdots c_{nm_n} \end{array} \\ \begin{array}{c} c_{12} \\ \vdots \\ c_{1m_1} \\ \vdots \\ c_{i1} \\ c_{i2} \\ \vdots \\ c_{im_i} \\ \vdots \\ c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{array} \begin{bmatrix} T_c^{11} & \cdots & T_c^{1j} & \cdots & T_c^{1n} \\ \vdots & & \vdots & & \vdots \\ T_c^{i1} & \cdots & T_c^{ij} & \cdots & T_c^{in} \\ \vdots & & \vdots & & \vdots \\ T_c^{n1} & \cdots & T_c^{nj} & \cdots & T_c^{nm} \end{bmatrix} \end{array} \tag{9}$$

The normalized total relation matrix T_c^{α} was obtained by normalizing T_c. The normalization process is illustrated by taking the submatrix T_c^{11} of equation (10) as an example. The row sum of elements in row i in T_c^{11} is denoted as d_i^{11}.

$$T_c^{11} = \begin{array}{c} \\ c_{11} \\ \vdots \\ c_{1i} \\ \vdots \\ c_{1m_1} \end{array} \begin{array}{c} \begin{array}{cccccc} & c_{11} & \cdots & c_{1j} & \cdots & c_{1m_2} \end{array} \\ \begin{bmatrix} t_{11}^{11} & \cdots & c_{1j} & \cdots & c_{1m_2} \\ \vdots & & \vdots & \cdots & t_{1j}^{11} \\ t_{i1}^{11} & \cdots & t_{ij}^{11} & \cdots & t_{im_2}^{11} \\ \vdots & & \vdots & & \vdots \\ t_{m_1 1}^{11} & \cdots & t_{m_1 j}^{11} & \cdots & t_{m_1 m_2}^{11} \end{bmatrix} \end{array} \begin{array}{l} \\ \\ \rightarrow d_1^{11} = \sum_{j=1}^{m_2} t_{1j}^{11} \\ \rightarrow d_i^{11} = \sum_{j=1}^{m_2} t_{ij}^{11} \\ \rightarrow d_{m1}^{11} = \sum_{j=1}^{m_2} t_{mij}^{11} \end{array} \tag{10}$$

Each element in row i of the matrix was divided by the sum of row i, and then the following normalized submatrix $T_c^{\alpha 11}$ was obtained:

$$T_c^{\alpha 11} = \begin{bmatrix} \frac{t_{11}^{11}}{d_1^{11}} & \cdots & \frac{t_{1j}^{11}}{d_1^{11}} & \cdots & \frac{t_{1m_2}^{11}}{d_1^{11}} \\ \vdots & & \vdots & & \vdots \\ \frac{t_{i1}^{11}}{d_i^{12}} & \cdots & \frac{t_{ij}^{11}}{d_i^{12}} & \cdots & \frac{t_{im_2}^{11}}{d_i^{12}} \\ \vdots & & \vdots & & \vdots \\ \frac{t_{m_1 1}^{11}}{d_{m_1}^{11}} & \cdots & \frac{t_{m_1 j}^{11}}{d_{m_1}^{11}} & \cdots & \frac{t_{m_1 m_2}^{11}}{d_{m_1}^{11}} \end{bmatrix} = \begin{bmatrix} t_{11}^{\alpha 11} & \cdots & t_{1j}^{\alpha 11} & \cdots & t_{1m_2}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{i1}^{\alpha 11} & \cdots & t_{ij}^{\alpha 11} & \cdots & t_{im_2}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{m_1 1}^{\alpha 11} & \cdots & t_{m_1 j}^{\alpha 11} & \cdots & t_{m_1 m_2}^{\alpha 11} \end{bmatrix} \tag{11}$$

The unweighted supermatrix W was obtained by transposing each normalized submatrix, where $W_{ij} = (T_c^{\alpha ji})^T, i = 1, 2 \ldots, n, j = 1, 2, \ldots n$.

$$W = \begin{array}{c} \\ D_1 \\ \\ \\ \\ \\ D_i \\ \\ \\ \\ \\ D_n \\ \\ \end{array} \begin{array}{c} \begin{array}{cccccccccc} & & D_1 & \cdots & & D_j & \cdots & & D_n & \\ & c_{11} & c_{11} & \cdots & c_{1m_1} & c_{j1} & \cdots & c_{jm_j} & c_{n1} & \cdots & c_{nm_n} \end{array} \\ \begin{bmatrix} W_{11} & \cdots & W_{i1} & \cdots & W_{n1} \\ \vdots & & \vdots & & \vdots \\ W_{1j} & \cdots & W_{ij} & \cdots & W_{nj} \\ \vdots & & \vdots & & \vdots \\ W_{1n} & \cdots & W_{in} & \cdots & W_{nn} \end{bmatrix} \end{array} \quad (12)$$

Step 2: Build the weighted supermatrix t_{ij}^{D}. Similar to the method used for processing the total relation matrix T_c based on the influencing factors, the total relation matrix T_d between dimensions was normalized to obtain the matrix T_d^{α}:

$$T_d^{\alpha} = \begin{bmatrix} \frac{t_{11}^d}{d_1} & \cdots & \frac{t_{1j}^d}{d_1} & \cdots & \frac{t_{1n}^d}{d_1} \\ \vdots & & \vdots & & \vdots \\ \frac{t_{i1}^d}{d_i} & \cdots & \frac{t_{ij}^d}{d_i} & \cdots & \frac{t_{in}^d}{d_i} \\ \vdots & & \vdots & & \vdots \\ \frac{t_{n1}^d}{d_n} & \cdots & \frac{t_{nj}^d}{d_n} & \cdots & \frac{t_{nn}^d}{d_n} \end{bmatrix} = \begin{bmatrix} t_{11}^{\alpha d} & \cdots & t_{1j}^{\alpha d} & \cdots & t_{1n}^{\alpha d} \\ \vdots & & \vdots & & \vdots \\ t_{i1}^{\alpha d} & \cdots & t_{ij}^{\alpha d} & \cdots & t_{in}^{\alpha d} \\ \vdots & & \vdots & & \vdots \\ t_{n1}^{\alpha d} & \cdots & t_{nj}^{\alpha d} & \cdots & t_{nn}^{\alpha d} \end{bmatrix} \quad (13)$$

The unweighted matrix W and dimension weight matrix of factors affecting public-public collaboration were calculated using equation (14) to obtain the weighted supermatrix W_w:

$$W_w = T_d^{\alpha} \times W = \begin{bmatrix} t_{11}^{\alpha d} \times W_{11} & \cdots & t_{i1}^{\alpha d} \times W_{1i} & \cdots & t_{n1}^{\alpha d} \times W_{1n} \\ \vdots & & \vdots & & \vdots \\ t_{1i}^{\alpha d} \times W_{i1} & \cdots & t_{ii}^{\alpha d} \times W_{ii} & \cdots & t_{ni}^{\alpha d} \times W_{in} \\ \vdots & & \vdots & & \vdots \\ t_{1n}^{\alpha d} \times W_{n1} & \cdots & t_{in}^{\alpha d} \times W_{ni} & \cdots & t_{nn}^{\alpha d} \times W_{nn} \end{bmatrix} \quad (14)$$

Step 3: Calculate the limit supermatrix for weights. The weighted supermatrix W_w was exponentiated until it converged to a stable state. When the elements in each row of the weighted supermatrix are the same, the matrix reaches a stable state. At this point, the limit supermatrix W^* shown in equation (15) was obtained, and the weight of each influencing factor was determined.

$$W^* = \lim_{k \to \infty} W_w^k \quad (15)$$

Based on the literature review and the actual situation of public-public collaboration for food safety risk management in China, a set of factors that affect public-public collaboration in the global context was constructed by the five dimensions, i.e., basic characteristics, legal basis, functions, behavior and capabilities, and infrastructure and culture of government agencies. First, the total relation matrix was divided by the set of influencing factors. Then, the resulting submatrices were normalized and transposed to obtain the unweighted supermatrix of factors affecting public-public collaboration for food safety risk management. The unweighted matrix and dimension weights of the influencing factors were calculated to obtain the weighted supermatrix W^{α} of the influencing factors. The limit of the weighted supermatrix was programed and calculated using MATLAB. The weighted supermatrix W^{α} was exponentiated until the results converged to the stable limit supermatrix W^* shown in **Table 5**.

Based on the calculation results of the limit matrix, the relative weights of each factor interacting in the whole factor set as shown in **Table 6** were obtained.

Analysis of Calculation Results

According to the above calculation results, the following analysis was conducted:

Interrelationships Between Dimensions and Identification of Key Dimensions

According to the data set $(f_i - e_i, f_i + e_i)$ for DEMATEL in **Table 4**, network diagrams of the relationships between the five dimensions and 20 factors were created as shown in **Figures 1**, **2**, respectively.

According to Chiu et al. (73), the value of $(f_i - e_i)$ is the main basis for determining the relationship between dimensions and identifying the cause and effect dimensions. Therefore, the relationships between dimensions and factors that affect public-public collaboration for food safety risk management can be analyzed based on the values of $(f_i - e_i)$ calculated in **Table 4**. As shown in **Table 4**, the $(f_i - e_i)$values of D_1 and D_3, i.e., 0.154 and 0.164, are positive, indicating that D_1 and D_3 more actively affect other dimensions in the system and thus can be identified as the cause dimensions. The values of $(f_i - e_i)$ of D_2, D_4, and D_5, i.e., −0.022, −0.166, and −0.130, are negative, indicating that D_2, D_4, and D_5 are more affected by other dimensions in the system and thus can be identified as the result dimension.

Figure 1 shows that the influence relationship between the five dimensions is $D_3 \rightarrow D_1 \rightarrow D_2 \rightarrow D_5 \rightarrow D_4$, $D_1 \rightarrow D_2 \rightarrow D_5 \rightarrow D_4$, $D_2 \rightarrow D_5 \rightarrow D_4$, and $D_5 \rightarrow D_4$ (where $\rightarrow$ indicates the direction of influence; the same definition is used below). These findings suggest that among the five dimensions affecting public-public collaboration for food safety risk management, D_3 has the greatest influence on the other four dimensions, and D_4 is most affected by the other four dimensions. D_1, D_2, and D_5 are both affected by and affect other dimensions, but the influences they received are greater than those they have over other dimensions. This result also suggests that the first step to achieve public-public collaboration for food safety risk management is to clearly define the functions of government agencies. It is necessary to minimize the blurring of functional boundaries and clarify their basic role types (comprehensive

TABLE 5 | Limit supermatrix of influencing factors.

Factors	d_1	d_2	d_3	d_4	d_5	d_6	d_7	d_8	d_9	d_{10}
d_1	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
d_2	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
d_3	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
d_4	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053
d_5	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047
d_6	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090
d_7	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
d_8	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099
d_9	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
d_{10}	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
d_{11}	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
d_{12}	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
d_{13}	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
d_{14}	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
d_{15}	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052
d_{16}	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041
d_{17}	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
d_{18}	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
d_{19}	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
d_{20}	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037

Factors	d_{11}	d_{12}	d_{13}	d_{14}	d_{15}	d_{16}	d_{17}	d_{18}	d_{19}	d_{20}
d_1	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
d_2	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
d_3	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
d_4	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053
d_5	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047
d_6	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090
d_7	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115	0.115
d_8	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099
d_9	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
d_{10}	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
d_{11}	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
d_{12}	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
d_{13}	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048	0.048
d_{14}	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
d_{15}	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052	0.052
d_{16}	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041
d_{17}	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
d_{18}	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
d_{19}	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
d_{20}	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037

dominant, single-function dominant, or auxiliary) and the power level, subordination, and professionalism.

Secondly, the basis for implementing public-public collaboration should be recognized by laws, regulations, and normative documents, etc.; the agency behavior and capabilities should be specified and regulated; and the infrastructure and culture should be improved to better support public-public collaboration.

According to Huang et al. (69), the size of influence weight and the positive or negative value of causality are the main basis for identifying key dimensions. Further analysis can be performed based on the data in **Table 6**. Among the system's five dimensions, D_2 has the highest influence weight (0.351), indicating that it has the greatest influence in the system of public-public collaboration for food safety risk management. Although its value of $(f_i - e_i)$ is −0.022, which is negative, it

TABLE 6 | Weights and ranking of factors affecting public-public collaboration for food safety risk management.

Object	Dimensions	Weights of dimensions	Factors	Weights of factors	Ranking
Public-Public collaboration for Food Safety Risk Management	D_1	0.133	d_1	0.038	15
			d_2	0.021	19
			d_3	0.020	20
			d_4	0.053	4
			d_5	0.047	10
	D_2	0.351	d_6	0.090	3
			d_7	0.115	1
			d_8	0.099	2
			d_9	0.048	7
	D_3	0.121	d_{10}	0.040	13
			d_{11}	0.033	18
			d_{12}	0.048	7
	D_4	0.197	d_{13}	0.048	7
			d_{14}	0.050	6
			d_{15}	0.052	5
			d_{16}	0.041	12
			d_{17}	0.042	11
	D_5	0.198	d_{18}	0.038	15
			d_{19}	0.039	14
			d_{20}	0.037	17

tends to 0, indicating that the influences it receives from the other four dimensions also tend to 0. Indeed, this is not difficult to understand because the basic characteristics, functions, behavior and capabilities, and infrastructure and culture of government agencies are all derived from the legal basis. The legal basis is the most authoritative and binding, and is stable in the long term. Therefore, it can be determined that the legal basis is a key dimension that plays a fundamental role among all dimensions.

Interrelationships Between Factors Affecting Public-Public Collaboration

The values of $(f_i - e_i)$ in **Table 4** reflect the degree of mutual influence among the system's 20 factors. Although these factors influence each other directly or indirectly, d_2 has the largest value of $(f_i - e_i)$ of 1.77 among all factors. It suggests that this factor has the greatest causality but varying degrees of influence on all other factors in the system, and thus can be identified as a cause factor. In contrast, d_{15} has the smallest value of $(f_i - e_i)$ (−0.243) among all factors, indicating that this factor has the smallest causality and is more affected by other factors in the system, and thus can be identified as an effect factor.

Figure 2 depicts the direct influence relationships between the factors that constitute the five dimensions. The values of $(f_i - e_i)$ of the four factors d_1, d_2, d_3, and d_4 that constitute D_1 are 0.404, 1.770, 1.625, and −0.395, respectively. Among them, d_2 has the largest value and thus can be considered the most influential factor in D_1. Hence, it can be concluded that the influence relationship between the four characteristic factors is as follows: $d_2 \rightarrow d_3 \rightarrow d_1 \rightarrow d_4$, $d_3 \rightarrow d_1 \rightarrow d_4$, and $d_1 \rightarrow d_4$. Likewise, the influence relationships between factors in the other four dimensions can be expressed in the same way as for those in D_1 (**Figure 2**). As shown in **Table 4**, with the values of $(f_i - e_i)$ being 1.170, 1.056, −0.380, and −0.243, d_5, d_9, d_{12}, and d_{20} are identified as the most influential factors in D_2, D_3, D_4, and D_5, respectively.

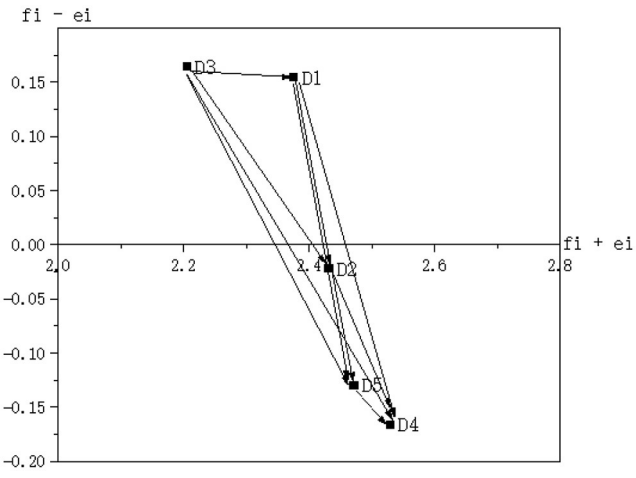


FIGURE 1 | Influence relation map of dimensions affecting public-public collaboration for food safety risk management.

Identification of Key Factors Affecting Public-Public Collaboration

Table 6 presents the influence weights of the five dimensions and 20 factors affecting public-public collaboration for food safety

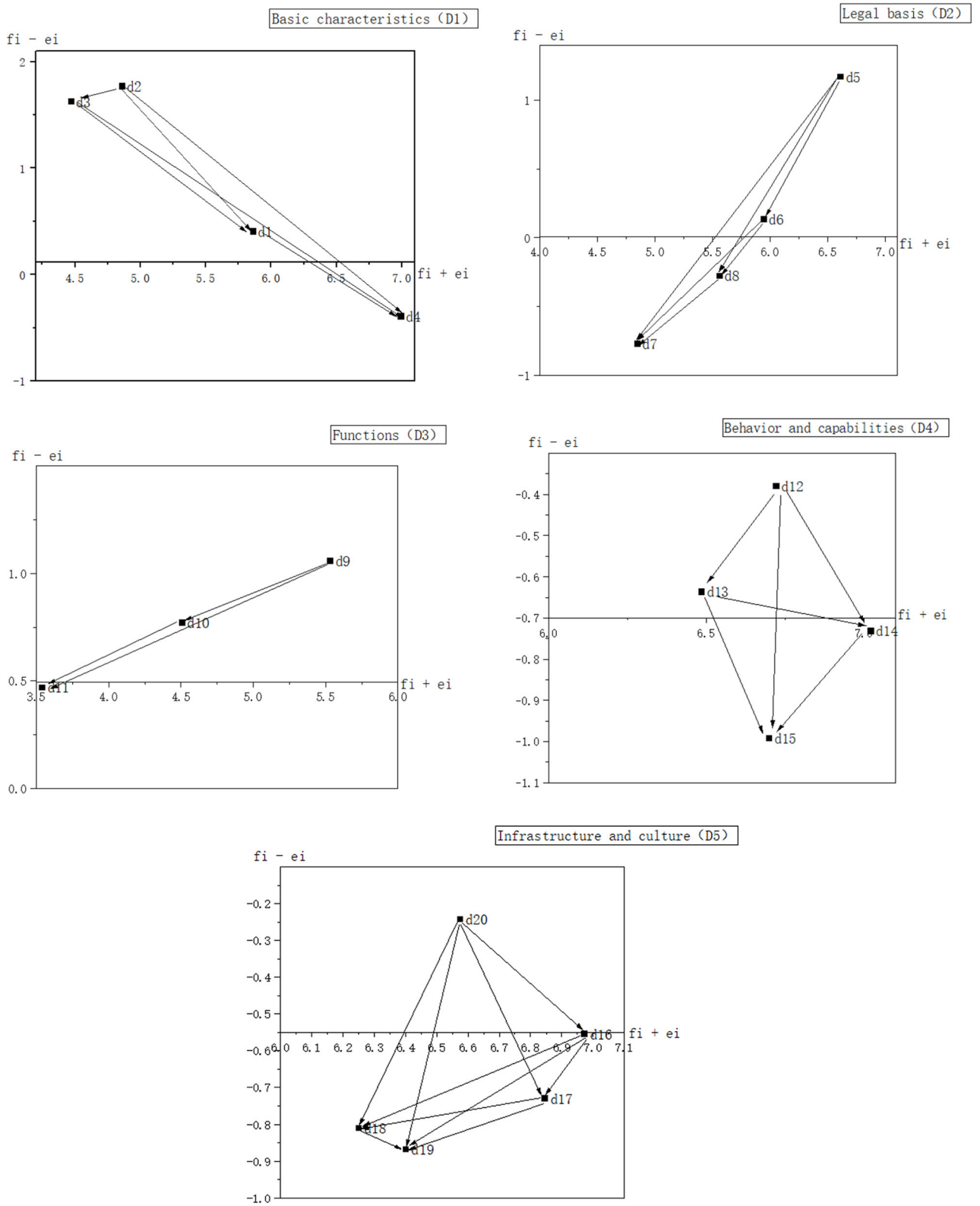


FIGURE 2 | Influence relation map of factors affecting public-public collaboration for food safety risk management.

risk management. Different criteria are needed for identifying key factors in a complex system composed of multiple factors. In general, taking into consideration the specific characteristics of the research object, key factors are identified in DANP, with the values of $(f_i + e_i)$ as the main criterion and the influence weight as the auxiliary criterion (74). Among the 20 factors in this system, d_{14} has the highest value of $(f_i + e_i)$ (7.022) and ranks sixth in terms of influence weight, indicating that this factor has the greatest combined influence on other factors. It demonstrates that the principle that "government must carry out all statutory functions and duties and may not do anything not authorized by law" plays an extremely important fundamental role in public-public collaboration. Hence, d_{14} is identified as a key factor. This is highly consistent with the conclusion of Gazley (57) that government agencies should implement public-public collaboration through legislative authorization.

The $(f_i + e_i)$ value of d_4 (6.993) ranks second and its influence weight ranks fourth, meaning that it can also be identified as a key factor. This is not only strikingly consistent with the actual situation of food safety risk management in China and Western countries, but also agrees with the findings of Woldesenbet (35). The $(f_i + e_i)$ value of d_{12} (6.722) ranks fifth, and its influence weight ranks seventh, so that it can also be identified as a key factor. This is because the effect of public-public collaboration among government agencies is determined by their comprehensive administrative capabilities, such as decision-making, execution, and coordination. This finding is consistent with the conclusion of Boatemaa et al. (55).

The $(f_i + e_i)$ value of d_{15} (6.699) ranks sixth, and its influence weight ranks fifth, indicating that food safety risk management depends on the improvement of the entire social environment and thus requires indirect participation by government agencies that perform auxiliary functions. This is consistent with the findings of Karp et al. (59). Hence, it can be identified as a key factor. The $(f_i + e_i)$ value of d_5 (6.614) ranks seventh, and its influence weight ranks tenth, indicating that this factor also exerts a certain influence on the system. This is because the legalization and institutionalization of government agencies' functions serves as a fundamental guarantee for the performance of their governance functions. This result is consistent with the conclusion of Koebele (41). Hence, it can also be identified as a key factor. To sum up, these are the five key factors affecting the governance capacity in public-public collaboration for food safety risk management.

It should be pointed out that although the $(f_i + e_i)$ values of d_{16} and d_{17} (6.973 and 6.864) rank third and fourth, respectively, their influence weights are relatively low, ranking twelfth and thirteenth, respectively. Therefore, it can be concluded that they have relatively limited combined influences and therefore should not be identified as key factors. Nevertheless, the ranking results do suggest that promoting information sharing and information technology is also important for public-public collaboration.

CONCLUSIONS, IMPLICATIONS FOR CHINA, AND PROSPECTS

Conclusions

Three conclusions can be drawn from the findings obtained from this study. First, public-public collaboration is affected by many dimensions and factors that interweave and interact with each other and form a complex system. Second, among the five dimensions, the legal basis has the highest influence weight, is the most critical dimension, and inherently affects the other four dimensions. This is because the principle that "government must carry out all statutory functions and duties and may not do anything not authorized by law" is a fundamental criterion for government agencies in modern society to have when performing their functions.

Third and lastly, among the 20 influencing factors, legislation-based governance, professionalism of government agencies, administrative law enforcement–based governance, social environment improvement–based governance, and having laws and regulations as legal basis are the most important factors. This is because government agencies implement public-public collaboration through legislative authorization. Moreover, because food safety risk management has high professional requirements, it is necessary to implement administrative law enforcement governance under the framework of legal authorization. Although informal rules are also valuable, public-public collaboration relies more on laws and regulations.

Implications for China

The conclusions of this study provide important guidance to the Chinese government. First, based on the essential requirements of food safety risk management in modern society, the capacity-building of legislative bodies should be strengthened to solve the problems of fragmentation of legislation and contradictions between laws to form a complete and interconnected system of laws and regulations. Efforts should also be made to improve the law enforcement environment and overcome local protectionism.

Second, although it is impossible to change the practice of using normative documents formulated by the government as a legal basis in the Chinese context, normative documents should be designed to minimize gaps and ambiguity in the legal system. It is also necessary to solve the problems of excessive and contradictory normative documents, and to abolish outdated normative documents in a timely manner to ensure that laws are not affected by normative documents.

Third, a hierarchical governance system for food safety management composed of government agencies with clear powers and responsibilities on the one hand and complementary functions from the central to the local levels on the other hand should be developed to solve the persistent problems in public-public collaboration, such as blurred boundaries, gaps, and fragmentation.

Fourth, efforts should be made to strengthen the professional development of government agencies to build a professional talent team and ensure adequate technical facilities. Fifth

and lastly, public-public collaboration for food safety risk management depends on the improvement of the entire social environment. It not only requires the efforts of dominant government agencies, including market regulation, agriculture and rural affairs, customs, and health agencies, but also the participation of auxiliary agencies such as those responsible for commerce, grain, forestry, and education. The above suggestions, especially building a complete legal system, strengthening the capacity-building of professional institutions, accelerating the adoption of information technology and infrastructure construction for food safety information systems, and promoting information flows among government agencies, also have implications for many developing countries.

Prospects

However, there are limitations in this study. The original data used in DANP were drawn from a Chinese expert group instead of a representative group of experts from different countries. The importance assigned to each dimension and factor largely depended on the observation or understanding of the situation of China by these Chinese experts. Moreover, Chinese characteristics were considered when determining the key dimensions and factors affecting public-public collaboration. For example, the use of government-issued normative documents (d_6) as a legal basis is apparently characteristic of China.

Therefore, the global applicability of this study's conclusions needs to be further assessed. Nevertheless, this study provides an approach for the academic community to use to understand the main problems facing public-public collaboration for food safety risk management in China, and it provides decision-making support for the Chinese government to promote public-public collaboration. Moreover, this study also has implications for many developing countries, especially that the government cannot simply replace laws with executive orders.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

All authors undertook research, writing, review tasks throughout this study, read, and agreed to the published version of the manuscript.

FUNDING

This work was supported by the National Social Science Fund of China: Research on Social Co-governance of Food Safety Risks and Cross-Border Cooperative Governance Mechanism (Grant No. 20&ZD117).

ACKNOWLEDGMENTS

The authors acknowledge the contributions of the editors and reviewers.

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frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 02 August 2022
DOI 10.3389/fpubh.2022.962629

Check for updates

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

RECEIVED 06 June 2022
ACCEPTED 18 July 2022
PUBLISHED 02 August 2022

CITATION
Wu L, Qin K and Chen X (2022) Responsibility of citizens in food safety social co-governance in the context of China. *Front. Public Health* 10:962629. doi: 10.3389/fpubh.2022.962629

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Responsibility of citizens in food safety social co-governance in the context of China

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Objective: This study aims to identify all actors that hold some responsibility for ensuring food safety based on the complete food supply chain in the context of China's current circumstances.

Methods: The study was conducted among citizens in Wuxi, Jiangsu, China. All citizens fully understood the purpose of the study and voluntarily agreed to participate. From December 10 to 14, 2020, a total of 398 valid samples were collected by the researchers using a structured questionnaire. Survey data were assessed using best–worst scaling and a mixed logit model from the perspective of citizen responsibility.

Results: In descending order, responsibility for ensuring food safety goes from food producers and traders (including producers, distributors, and retailers) to the government, social organizations, news media, and finally to citizens. Food producers and traders are the actors who should take the greatest responsibility, whereas citizens bear the least responsibility.

Conclusion: The responsibility of citizens in food safety co-governance should be recognized but it should not be arbitrarily extended.

KEYWORDS

food safety social co-governance, responsible actor, citizen responsibility, mixed logit, best-worst scaling (BWS)

Introduction

Food safety is a major public issue facing all countries around the world (1, 2), and it has been identified as a public health priority by the World Health Organization (3). Numerous studies and practical experiences have demonstrated that as industrialization proceeds, production technologies become more and more complex, and the food industry structure become increasingly advanced. In this context, even a small food safety risk has the potential to threaten consumer dietary health throughout the food supply chain due to the butterfly effect (4, 5). Therefore, government or market failures, either alone or combined, are difficult to avoid by relying solely on these actors (acting alone or together) to manage food safety risks. Thus, the traditional governance model has been unable to effectively meet society's consumption needs regarding food safety (6, 7). Ensuring food safety is therefore the common responsibility of all stakeholders, which requires each of them to perform their respective functions (8). The phenomenon of

social co-governance first emerged in the 1960s and 1970s and has since developed as a new governance model in Western countries. It evolved in response to changes in the relationship among government, market, and society (9). In brief, a food safety social co-governance system enables all stakeholders, including the government, enterprises (market), social organizations, and citizens, to fulfill their respective responsibilities in accordance with the law, participate in the formulation and revision of food safety laws, regulations, and rules in different manners, and coordinate and cooperate with each other, thereby collectively ensuring food safety with low governance costs in an open, transparent, and flexible manner (10). Although China has different national conditions from those in Western countries, the Chinese government began to reform the country's food safety governance model in 2013, especially in 2015 and through the revised Food Safety Law, which identified social co-governance as the basic mechanism for managing food safety risks (11). However, at present, there are still serious deficiencies in the construction of a food safety social co-governance system in China. One such important aspect is that most citizens regard themselves simply as food consumers. They seldom actively participate in the supervision of food production and distribution and do not actively engage with or lack channels through which to participate in the formulation of government food policies (12). Most consumers even keep silent when harmed by defective food products. However, individuals are the best judges of their own actions (13). Because food safety is a major public issue related to individual health and social stability, each citizen can be considered a natural and unique participant in the food safety social co-governance system, wherein citizens have unique functions that differ from those of government, market, and social organizations. A food safety social co-governance system cannot exist without citizens' active and broad participation. Therefore, this study includes citizen responsibility in the food safety social co-governance system to investigate the responsibilities of all key responsible actors, including citizens, in ensuring food safety in the context of China, and objectively evaluates citizens' responsibilities in the food safety co-governance system, with a view to ensuring that citizens are willing and able to participate in food safety co-governance, which is the long-term solution to ensuring food safety.

Ensuring food safety is one of a government's basic responsibilities (14). Government responsibility has become an important symbol of a democratic political system. However, the high cost of government regulation provides space for opportunistic behaviors by producers and traders, resulting in frequent food safety incidents (15). In China, the government is coming under increasing pressure from regulations and public opinion as food safety issues become increasingly complex. Increasingly, all food safety problems are being attributed to inadequate government regulation (16). Therefore, given the increasingly complex food safety risk factors, it is necessary to change the traditional government-based one-way governance structure, rely more on the cooperation of multiple stakeholders, such as the government, enterprises, and the public, and develop good citizenship by activating social forces, mobilizing broad public participation, and increasing citizen engagement (17, 18). Despite the current overall trend of improving food safety in China, food safety risks are highly complicated due to the interconnections of pre-market and market risks and integration of traditional and new risks (19), making decision-making in risk governance complicated for the government. In terms of long-term governance, this responsibility clearly cannot be borne entirely by the government, but should be spread across stakeholders (20). In fact, every citizen has a responsibility for considering food safety along the entire process from farm to fork (21). As food consumers, the public is also a stakeholder and should participate in food safety social co-governance (22). However, there is a conspicuous absence of responsibility among Chinese citizens, including the lack of a public responsibility culture, low participation rate, and difficulty in maintaining enthusiasm for participation (23). Moreover, due to the frequent occurrence of food safety incidents over a long-term period, Chinese citizens now lack confidence and trust in food safety, which has become an important obstacle for them to effectively participate in food safety social co-governance (24). Instead, citizens only tend to pay attention to food safety when a food scandal comes to light (25). In addition, Shang et al. (26) found that most citizens lacked basic knowledge about, had a low willingness to pay for, and took a wait-and-see attitude toward traceable food, which makes it difficult to establish a traceable food market in China. This indifferent attitude also exists in other countries. Mensah et al. (27) found that ordinary citizens in Ghana often turn a blind eye to street food vendors with hygiene problems. Wiatrowski et al. (28) conducted a survey study in Poland and found that most respondents did not care about the hygiene of street food.

In fact, citizenship entails responsibilities. Participation in public affairs is an inherent duty of citizenship (29). However, citizens are overly dependent on the government, lack due understanding of their own responsibilities in public crisis management, and have not had their sense of responsibility and ability developed adequately, resulting in the government being overloaded with responsibilities (30). In terms of food safety risk management in China, consumer protection has always been emphasized in legislation and practice. Although this practice is beyond reproach, it has long neglected the cultivation of a sense of responsibility among consumers, resulting in common unawareness of consumer responsibility (31). However, consumers should not simply be viewed as a vulnerable group to be sympathized with or protected. Consumers' awareness of their responsibilities and abilities regarding food safety will help the government to act in a correct and responsible manner (12). Xue and Zhang (32)

found that up to 70% of fatalities due to home-acquired food poisoning in China were caused by improper food handling by household members. Consumers' literacy and abilities in relation to food safety affect their individual and household's food safety (33). Bakhtavoryan et al. (34) found in the case of a 2007 peanut butter recall in the United States that American consumers responded quickly to foodborne disease outbreaks, which motivated companies to improve their food safety emergency management system. Therefore, in addition to the strong government measures, citizens should actively cooperate with the implementation of food safety governance policies and assume their responsibilities to consciously protect public interests in food safety (35).

Citizens can play a critical role in food safety risk management (36). Accordingly, solving the issues of how to mobilize citizens to participate in co-governance and how to reconstruct the food safety governance structure to make citizens an important participant are central for China's efforts to build a food safety social co-governance system (37). The results of previous studies have important implications for the present study. However, this research area is still in its infancy in mainland China. Due to differences in cultural practices and economic development, the conclusions of studies performed outside China may be unable to explain the special problems in food safety risk management in large developing countries like China. The applicability of these conclusions to China needs to be further examined.

In this study, we attempted to incorporate citizens into the food safety social co-governance system, and scientifically identify the key responsible actors, including the government, enterprises, social organizations, and citizens, in the co-governance system. Moreover, we investigated the responsibilities of these key actors for ensuring food safety and objectively evaluated citizens' responsibilities in the food safety co-governance system in the context of China using best–worst scaling (BWS) and a mixed logit model, thereby eliciting the policy implications for enabling citizens to play their role in China, which is an innovative perspective and methodology.

Materials and methods

Categories of responsible actors

Many traditional stakeholders exist in food safety. Meanwhile, the continuous development of online trading has seen the emergence of trading platforms and WeChat Moments, etc., as new stakeholders. Nevertheless, as early as 1995, the Commission on Global Governance (CGG) put forward a generally accepted view based on extensive academic research, namely that the government, food producers and traders, social organizations, and citizens are the four fundamental types of responsible actors in the food safety co-governance system in Western countries (38). Other stakeholders can be categorized as one of these types according to their functions. For example, online food trading platforms are essentially retailers. At present, responsible actors in food safety social co-governance system in China have been classified according to different schemes into three, five, or seven types (39–41). Based on China's current conditions and the findings of previous studies, this study suggests that the government, food producers and traders, social organizations, news media, and citizens are the five fundamental types of responsible stakeholders in the country's co-governance system. They can be further divided into seven actors with basically clear boundaries and relatively independent functions. These actors are detailed as follows.

Food producers and traders

The most basic element of food safety is production, i.e., all steps of the production process before food reaches consumers' plates. Ensuring food safety thereby requires combined efforts from producers, distributors, and retailers, all of whom are indispensable. These three actors have clear boundaries and are mutually irreplaceable. Together, they constitute the whole process from farm to fork. As the actors most directly involved in ensuring food safety, they should hold primary responsibility for jointly ensuring food safety (42), in keeping with common practice around the world (43). Therefore, in this study, food producers, distributors, and retailers are regarded as three independent actors who share the primary responsibility for food safety, thereby increasing the number of actors from five to seven in this paper.

Government

Food safety also relies on governance. As a major public health issue, food safety risks are the shared responsibility of governments around the world (44). In China, food safety has been identified as a major issue in terms of both livelihood and politics and therefore requires coordinated efforts from all levels of government. Of course, governments in different countries have enacted very different systems for managing food safety risks. For example, the Food and Drug Administration, founded in 1906, is the only department of the U.S. government that implements food safety regulations. In China, food safety regulators have undergone dynamic changes since the reform and opening up. Before 2013, multi-department governance had been employed. For example, approximately 10 government departments participated in the management of pork from farm to fork. After two reforms in 2013 and 2019, a regulation system based on three departments, including the Ministry of Agriculture and Rural Affairs, market regulation department, and health department, was developed, with the participation of more than 10 other departments. Therefore, government regulators are more or less substitutable with each other. Given

the changes in government regulation of food safety in China, this study regards all such multiple government regulators as a whole in terms of performing regulatory functions on the government's behalf.

Social organizations

Social organizations are diverse in form and function. Based on the classification used in Western countries as well as the current situation of China, this study divides social organizations that can play a role in the co-governance system into the following four types. The first type is professional food industry organizations. In China, such organizations include food industry associations, food fermentation associations, etc., which have professional, industry-specific, and self-disciplined functions in food safety co-governance. The second type is food testing organizations. Such organizations have been entrusted with inspecting the quality of food produced by enterprises. Although an entrusted passive behavior, it has higher credibility. Especially in the case of disputes, it plays a greater role than the active inspection of industry and consumer associations (45). The third type is food certification and accreditation organizations. Such organizations investigate and supervise food producers and traders in accordance with the law, and make recommendations to the government or relevant organizations about revoking the qualifications of enterprises that no longer meet the requirements (46). Finally, the fourth type is consumer organizations. Such organizations are non-governmental organizations founded by consumers to communicate with producers and traders in order to maintain their own rights and interests (47). They have wide coverage and great influence, performing an important social function in terms of protecting the rights and interests of consumers (48). It should be pointed out that although these four types of social organizations have different functions and responsibilities, there are no absolute boundaries between them, and they are mutually substitutable to a certain extent. For example, professional food industry organizations can also accept complaints from consumers and carry out some of the same functions as consumer organizations; they may also function as food testing organizations. Therefore, these social organizations are merged into one actor in the co-governance system in this study.

News media

News media can take advantage of their strong influence and rapid information dissemination capabilities to alleviate food safety information asymmetry to a certain extent. For example, the melamine-tainted milk powder crisis was widely reported by different types of news media within 4 months of its outbreak in August 2008. The incident's huge scale not only caused a sensation in China, but also attracted extensive attention from the international community. On the one hand, the strong public opinion motivated government regulators to enhance food safety regulation. On the other hand, online public opinion began to be noticed by a wide range of citizens at different levels in China, which initiated the process of mobilizing citizens to participate in food safety risk management. As such, the news media can act as a "vanguard" and "watchmen" in the food safety social co-governance system in China (46, 49). News media can be considered a social organization, and it enjoys an independent legal status. Like professional food industry organizations, media outlets have the function of communicating with the government, food producers and traders, and society, and serve as an important bridge to overcome government and market failures (50). In this study, the media is regarded as an individual actor rather than being included into the category of social organizations. This is not only because the media lacks the professional competencies of food industry organizations, but more importantly, most news media outlets have some attributes of government organizations in the context of China. They have a unique function different from those of any other types of social organizations in the co-governance system. This is an important distinction from Western countries. In Western constitutional theory, the separation of legislative, executive, and judicial powers is an institutional design to restrict government power. The regulatory power of the media is called the fourth power in addition to these three powers (18).

Citizens

As indicated in the literature review, citizens capable of independent behavior are not simply food consumers. They not only should assume the responsibility of self-protection, but can also act as the best participant and regulator of food safety. As such, they are an important force in social co-governance, playing an irreplaceable role. In the context of China, a citizen is a person who has citizenship and thus has certain rights as well as obligations. It represents the concept of an individual. However, in this study, citizens included in the co-governance system to assume the corresponding responsibility are a collective concept, representing a collection of individual citizens.

To sum up, this study develops an analytical framework shown in Figure 1 based on the reality of China. This study suggests that the government, food producers and traders, social organizations, news media, and citizens are the five fundamental types of responsible stakeholders in the co-governance system. Moreover, food producers and traders are subdivided into three basic actors, i.e., producers, distributors, and retailers, which have clear boundaries and are not mutually replaceable, together constituting the whole food supply chain from farm to fork. As the actors most directly involved in ensuring food safety, they should hold primary responsibility for jointly ensuring food safety. However, it is far from enough to rely solely on food producers and traders to ensure food safety as it is impossible for them to take responsibility totally on their own initiative.

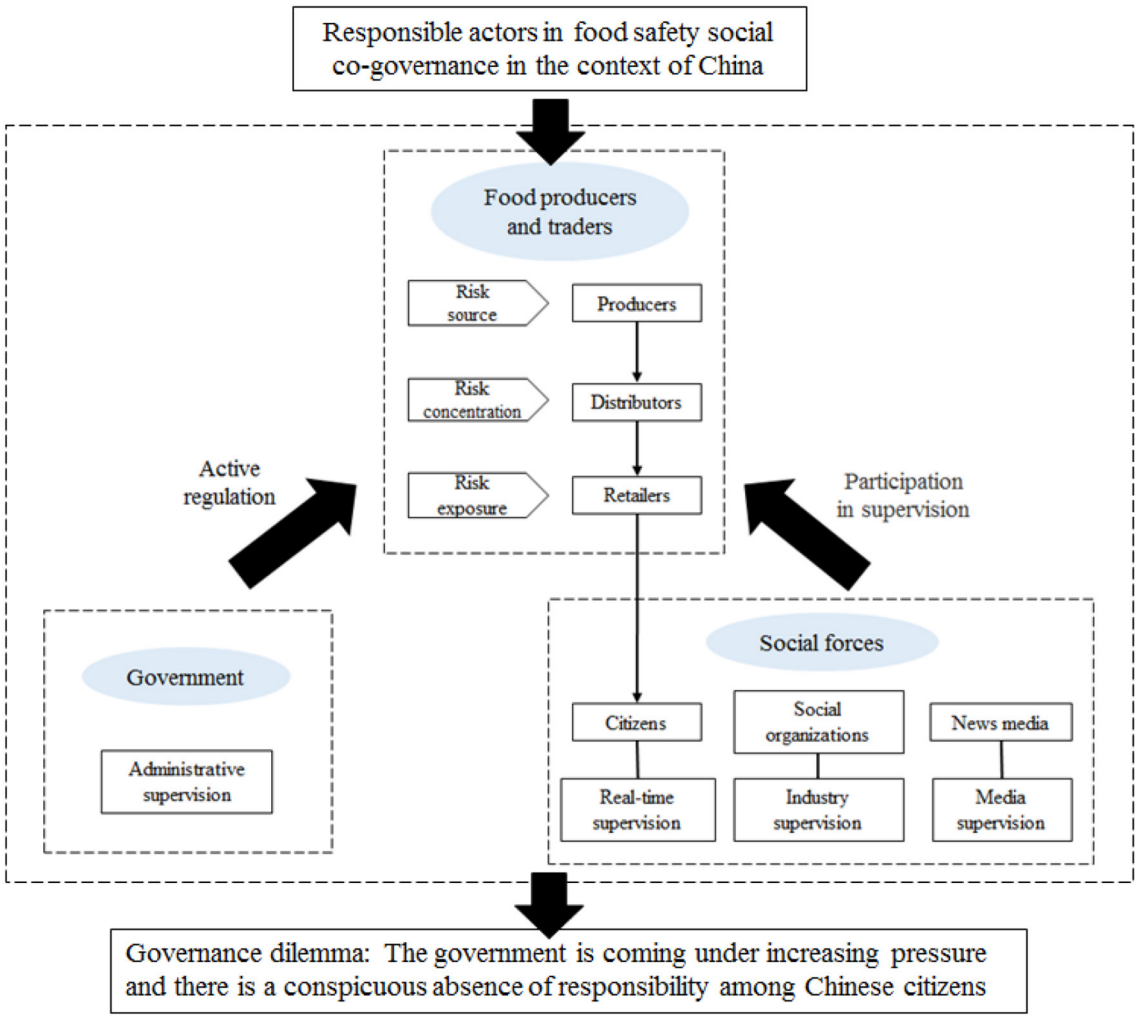


FIGURE 1
Research framework.

Due to the intertwining of objective factors, such as science and technology, and ecological environment, with human factors, food safety risks are superimposed over one another in different parts of the supply chain, which will induce food safety incidents and aggravate the harm of food safety risks. The management of food safety risks is the common responsibility of all stakeholders, and requires the joint participation of the government and social forces. China is in the midst of drastic social changes. The food safety risks it faces have inherent characteristics different from those of Western countries. The Chinese government is not only faced with the scarcity of governance resources, but also with heavy regulatory tasks. As an important social force, citizens should take the initiative to assume their responsibilities. However, there is in fact a conspicuous absence of responsibility among Chinese citizens. Therefore, this study investigates the responsibilities of key responsible actors in ensuring food safety in the context of China, and objectively evaluates citizens' responsibilities in the food safety co-governance system with a view to providing guidance for the Chinese government to develop institutional arrangements for citizens to play a role in managing food safety risks.

Sample and data collection

The data for this study were collected by a questionnaire survey. Wuxi in Jiangsu Province has been among the leading large and medium-sized cities in China in terms of economic and social development. In 2020, Wuxi had the highest per capita GDP among all cities in China. Ordinary people generally live in good conditions and show relatively high satisfaction with food safety. This area therefore provides a good foundation for

this study. Sample data were collected from a field questionnaire survey in the five administrative districts of Wuxi, including Liangxi, Xishan, Huishan, Binhu, and Xinwu districts. The sample size for each district was proportional to the respective resident population. The survey was carried out among citizens aged over 18 years (hereinafter referred to as respondents) in farmers' markets, chain supermarkets, and food stores with a large flow of customers in each district. Investigators were instructed to select the third person coming into view as a respondent to maximize sample randomness (51). The questionnaires were completed anonymously by respondents at the survey sites and collected once completed. The entire survey process was completed in the period December 10–14, 2020. A total of 398 valid samples were collected.

Measures

BWS, also known as maximum difference scaling (MaxDiff), is an extension of pairwise comparison (52). As an important method to investigate professional issues, such as psychological values, consumer preferences, and corporate social responsibility (53–55), BWS asks respondents to select the "best" and "worst" items from a set of options based on their personal perceptions. Erdem and Rigby (56) pointed out that respondents' choices of "best" and "worst" items will maximize the difference in their preferences, thereby allowing identification of the set of preferences for a specific option based on group selection of that option by different respondents. Generally speaking, when methods such as the Likert five-point scale are used to elicit preferences, respondents may have ambiguous choices when faced with five different options due to differences in understanding. This problem can be avoided by using BWS. However, measuring multi-level preferences by having respondents identify their choices of best and worst items using BWS can effectively eliminate the measurement error between different preference levels (57). This allows accurate ranking according to respondents' preferences (58), ensuring that conclusions are more in line with reality (59, 60). Accordingly, this study attempts to determine the responsibilities of all stakeholders in the entire food supply chain according to citizens' preferences using BWS in combination with the mixed logit model, thereby better reflecting citizens' perceptions of their own responsibilities.

According to Louviere et al. (61), offering more than five options may fatigue respondents and thus may lead to a preference bias. Therefore, using SSIWeb 7.0 software, the questionnaire was designed so that, first, the seven responsible actors were randomly combined into seven choice groups. Then, a balanced incomplete block design (54) was used to ensure that the options in each choice group satisfy the orthogonality. Each choice group included three actors to choose from. The number of occurrences of each actor in the questionnaire was the same (three times). Respondents were asked to select one of the three actors in each group that should bear the most or the least responsibility. Table 1 is a sample questionnaire designed based on BWS.

TABLE 1 Sample questionnaire designed based on BWS.

Actor that should bear the greatest responsibility	Options	Actor that should bear the least responsibility
☐	Government	☐
☐	Food distributors	☐
☐	News media	☐

Results

Measurement model

The mixed logit model is based on random utility maximization and is a generalization of the traditional multinomial logit model. Compared with the traditional multinomial logit model, the mixed logit model relaxes the strict assumption of independence of irrelevant alternatives, allows coefficients to differ between samples with the same observable characteristics, and does not assume that error terms follow a normal distribution (62, 63). Therefore, the mixed logit model provides a better fit than the traditional multinomial logit model, while highlighting the preferences of different individuals (63). Moreover, it is especially effective when the same respondent is required to make multiple repeated choices (64).

According to the random utility maximization theory, it is assumed that the utility $Unkt$ obtained by individual n ($n = 1, 2, \ldots, n$) from choosing the kth ($k = 1, 2,..., k$) alternative in situation t ($t = 1, 2, \ldots, t$) can be divided into two parts. The first part is the observable fixed utility, which depends on the observable attributes of the alternative and individual characteristics. The second part is the unobservable random utility, which represents the effect of unobservable factors on an individual's choice. The utility expression is as follows:

$$Unkt = Vnkt + \varepsilon nkt = \beta nktXnkt + \varepsilon nkt \quad (1)$$

where $Unkt$ is the utility obtained by individual n from choosing k in situation t; $Vnkt$ is the observable utility; $Xnkt$ is the attribute variable of actor k, which is the observable explanatory vector; and βn and εnkt are the random-effect variables that cannot be directly measured.

In the BWS study, respondents were asked to choose the pair of actors with the largest utility difference, i.e., the actors that should bear the greatest and least responsibility. For

example, assuming that respondents chose actors i and j to bear the greatest and least responsibility, respectively, the utility difference between $Unit$ and $Unjt$ is then greater than that of all other choice sets M, where $M = K(K-1)-1$. By assuming εnkt follows an independent and identically distributed type I extreme-value distribution, the following choice probability of the conditional logit model can be derived:

$$P(i,j) = \frac{\exp(Vnit - Vnjt)}{\sum_{l=1}^{K}\sum_{m=1}^{K}\exp(Vnlt - Vnmt) - K} \quad (2)$$

where i is the actor chosen to bear the greatest responsibility, and j is the actor chosen to bear the least responsibility. When respondents choose a range of actor combinations that should bear the greatest and least responsibility in situation t, the choice probability of Equation (2) can be expressed as follows:

$$Ln(\beta n) = \prod_{t=1}^{T} \frac{\exp(Vnit - Vnjt)}{\sum_{l=1}^{K}\sum_{m=1}^{K}\exp(Vnlt - Vnmt) - K} \quad (3)$$

The mixed logit probability is a weighted average of each logit variable in the estimation of different β values. The weights are given by the density function $f(\beta n|\, b, w)$. The choice probability of Equation (3) can then be expressed as

$$Pn = \int Ln(\beta n) f(\beta n|\, b, w) d\beta n \quad (4)$$

Descriptive analysis results

Respondent demographics are shown in Table 2. There were more females than males in the sample, which is consistent with the fact that in China, most household food purchasers are female. Most respondents were married (70.4%), aged 26–35 (47.0%), had a bachelor's degree (32.9%), had a personal annual income of more than 100,000 yuan (30.7%), and had a household size of (41.0%). In terms of occupation, company employees accounted for the highest proportion (49.5%). In addition, 58.0% of the respondents had children under 18 in the household.

Mixed logit model analysis results

The assignment of responsibilities to each responsible actor in the food safety social co-governance system for ensuring food safety was performed using the utility code (Table 3).

TABLE 2 Demographics of respondents.

Group	Sample size (n)	Proportion (%)
Gender		
Male	158	39.7
Female	240	60.3
Age (year)		
18–25	74	18.6
26–35	187	47.0
36–45	104	26.1
46–55	25	6.3
>55	8	2.0
Marital status		
Married	280	70.4
Unmarried	118	29.6
Education		
Junior high school or lower	37	9.3
High school	92	23.1
Junior college	125	31.4
Bachelor's degree	131	32.9
Master's degree or higher	13	3.3
Personal annual income (yuan)		
<36,000	62	15.6
36,000–50,000	88	22.1
50,000–80,000	79	19.8
80,000–100,000	47	11.8
>100,000	122	30.7
Household size (n)		
1	4	1.0
2	18	4.5
3	163	41.0
4	118	29.6
5 or more	95	23.9
Occupation		
Government or public institution employee	38	9.5
Company employee	197	49.5
Farmer	11	2.8
Self-employed/unemployed/retired	128	32.2
Student/graduate student	24	6.0
Having children aged under 18 in the household		
No	167	42.0
Yes	231	58.0

TABLE 3 Assignment to responsibility variables.

Variable	Assignment
Food producers	Actor that should bear the greatest responsibility = 1; Actor that should bear the least responsibility−1; No option = 0
Food distributors	Actor that should bear the greatest responsibility = 1; Actor that should bear the least responsibility−1; No option = 0
Food retailers	Actor that should bear the greatest responsibility = 1; Actor that should bear the least responsibility−1; No option = 0
Government	Actor that should bear the greatest responsibility = 1; Actor that should bear the least responsibility−1; No option = 0
Social organizations	Actor that should bear the greatest responsibility = 1; Actor that should bear the least responsibility−1; No option = 0
News media	Actor that should bear the greatest responsibility = 1; Actor that should bear the least responsibility−1; No option = 0
Citizens	Actor that should bear the greatest responsibility = 1; Actor that should bear the least responsibility−1; No option = 0

TABLE 4 Mixed logit model estimates.

Responsible actors	Mean	Standard deviation	Responsibility share (%)
Food producers	0.521	0.016	20.81
Food distributors	0.032	0.008	9.67
Food retailers	0.297	0.009	11.59
Government	0.813	0.008	28.19
Social organizations	0.385	0.014	13.90
News media	−0.496	0.015	9.30
Citizens	−0.907	0.021	6.54

The mixed logit model estimates are presented in Table 4. The mean and standard deviation of each variable indicate respondents' perception changes and differences in perceptions regarding the different actors responsible for ensuring food safety, respectively. The greater the standard deviation, the greater the heterogeneity of respondents' perceptions. Analysis of the data in Table 4 demonstrated that, in descending order, the responsibility among the seven actors in the food safety social co-governance system went from the government to producers, social organizations, retailers, distributors, news media, and citizens. The government, producers, and social organization were considered to hold an above- average level of responsibility, where the average was defined by equally allocating the responsibilities to the seven actors. In contrast, respondents assigned a below-average level of responsibility to retailers, distributors, news media, and citizens. Among them, citizens were considered the actor that should bear the least responsibility in the co-governance system.

Discussion

Among the seven actors of the five types, food producers, distributors, and retailers together constitute a combined actor, namely food producers and traders. The results in Table 4 indicate that food producers and traders should bear 42.07% of the responsibility in the co-governance system, making it the actor that should bear the greatest responsibility for food safety. This conclusion is completely consistent with the requirements of general international rules and current Chinese food safety laws and regulations, as well as the conclusions of Kleter and Harris et al. (65, 66). However, the responsibilities borne by food producers, distributors, and retailers in the whole process from farm to fork are not the same, and can be individually allocated as 20.81, 9.67, and 11.59%, respectively. In other words, producers have the greatest responsibility, followed by retailers, and distributors bear the least responsibility.

The government should bear 28.19% of the responsibility, which is the second greatest share of responsibility after that of food producers and traders. In addition, social organizations and news media should bear 13.90 and 9.30% of responsibility, respectively, which are considerable shares. As explained above, the news media is regarded as an individual actor because most news media outlets in China have some attributes of government organizations despite being different from government regulators; they also have a unique function that is different from those of any other types of social organizations in the co-governance system. However, news media is also a social organization with an independent legal status. In this sense, the responsibility share of all social organizations, including news media, for food safety co-governance, was 13.90%, which is the third greatest share.

In addition, the responsibility share of citizens was 6.54%, which is the smallest share in the co-governance system. This is consistent with the conclusions of Erdem et al. (58) and is related citizens' position at the of the food supply chain. It also coincides with the reality that Chinese citizens have a weak sense of participation. At present, in China, citizens mainly participate

in food safety by complaints and passive reporting after the discovery of defective food products. This reflects the fact few channels exist for Chinese citizens to participate in food safety governance in advance.

However, some controversy still exists in the literature regarding whether citizens are the actor with the least responsibility in the food safety social co-governance system. Redmond and Griffith (67) and Van et al. (68) believed that citizens should bear a great responsibility for food safety. Kjaernes et al. (69) even argued that citizens had a greater responsibility than the government. This discrepancy may arise from differences in the sense of citizenship and food safety regulation systems between countries, and it may also be related to differences in the samples studied and the effects of interest demands of respondents on the empirical results (70). Although the present study is based on data obtained from a citizen survey, it is an objective fact that citizens may ignore or shirk their responsibility, thus resulting in impaired objectivity. Therefore, on the one hand, the responsibility of citizens in terms of food safety co-governance should be objectively recognized, but on the other hand, it should not be arbitrarily extended. Appropriate judgments should be made based on the actual situation. The conclusions of this study provide useful guidance for improving China's food safety social co-governance system. This study argues that although it is important for food producers and traders, the government, social organizations, and news media to shoulder their responsibilities and for continuous efforts to be made to improve laws and regulations to protect citizens' rights in food consumption, citizens should no longer be regarded simply as consumers. Specifically, efforts should still be made to encourage citizens to submit complaints and reports when confronted with food safety problems. But more importantly, at the institutional level, more diversified channels should be designed to ensure that citizens participate in the supervision of food safety in production and marketing, discuss government food safety policies, and develop scientific literacy regarding food safety, so that citizens at different levels will have both the willingness and ability to participate in food safety co-governance. This would not only help build a food safety social co-governance system in China, but is also an inherent requirement of exploring democracy. If the government is able to create a favorable social environment for citizen participation and design channels for citizen participation at the institutional level in the future, it will greatly improve their sense of responsibility and promote their participation in food safety social co-governance. Nevertheless, citizens' responsibilities in food safety social co-governance should not be over-exaggerated.

There are limitations in this study. First, the survey for this study is geographically limited to Wuxi and is not nationwide due to time and fund constraints. Moreover, the demographics of the sample do not perfectly match the overall demographics of Wuxi. Future research should expand the survey area to examine the differences in the public's responsibility perception in different areas to make improvement in depth and breadth. Second, there is no clear division of power and responsibility in the entire food supply chain between the government, market, and society. The role of any individual actor has spatial and temporal boundaries, which, however, are relative and limited, leading to the ambiguity of responsibilities. Therefore, there is still some overlap in the functions undertaken by the seven actors identified in this study in ensuring food safety. This is not only a limitation of this study, but also an unbreakable fact that exists in all countries. Third and lastly, some controversy still exists in the literature regarding whether citizens are the actor with the least responsibility in the food safety social co-governance system. As the present study is based on data obtained from a citizen survey, it is possible that the conclusions may suffer impaired objectivity because citizens may consciously ignore or shirk their responsibility due to their own interest demands. Therefore, future research should include a survey of all responsible actors using new methods to allow a more objective assessment of the responsibilities of all responsible actors, including citizens, in ensuring food safety.

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 human participants were reviewed and approved by Jiangnan University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

LW conceptualized the study. KQ processed and analyzed the relevant data, as well as wrote the manuscript. XC collected and analyzed the relevant data and revised the manuscript. All authors contributed to the study design, interpretation the results and manuscript revision, and have approved the final manuscript.

Funding

This study was supported by the National Social Science Fund of China: Research on social co-governance of food

safety risks and cross-border cooperative governance mechanism (20&ZD117).

Acknowledgments

The authors acknowledge the contributions of the editors and reviewers.

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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frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 25 August 2022
DOI 10.3389/fpubh.2022.985576

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OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

RECEIVED 04 July 2022
ACCEPTED 08 August 2022
PUBLISHED 25 August 2022

CITATION
Xia W, Wang Z, Zhang J, Yu J, Qiu L and Yang Z (2022) Structural characteristics of China's COVID-19 patent cooperation network at the province, city, and patent applicant levels. *Front. Public Health* 10:985576. doi: 10.3389/fpubh.2022.985576

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Structural characteristics of China's COVID-19 patent cooperation network at the province, city, and patent applicant levels

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The Chinese Plan has provided an important model for the global fight against COVID-19 since its outbreak. The present study describes the structural characteristics of China's COVID-19 patent cooperation network at the province, city, and applicant levels by using social network analysis based on data from the Incopat global patent database since 2020, which helps to clarify the current technology accumulation in this field in China, and provide patent information support for the scientific efforts to fight against COVID-19. The findings are as follows: First, the inter-regional cooperation level in China's COVID-19 patent cooperation network shows a decreasing trend from eastern to central to western regions. At the inter-applicant cooperation level, kinship-based cooperation is the strongest, business-based cooperation has the widest scope, while proximity-based cooperation exists throughout these two main models of cooperation. Second, coastal provinces and cities occupy a core position in the network, and play an important role in utilizing structural holes and bridging. Patent applicants with high centrality are mostly firms. Research institutes and universities mainly play the role of bridges. Third and lastly, there is no large number of cliques at the province and city levels. However, there is a tendency for cliques to develop at the applicant level. Hence, actions are needed to prevent the development of information barriers.

KEYWORDS

COVID-19, patent cooperation, social network, China, structural characteristics

Introduction

The outbreak of Coronavirus Disease 2019 (COVID-19) at the end of 2019 has seriously threatened human health. Research teams and pharmaceutical companies around the world are stepping up to develop related products to fight against COVID-19. Meanwhile, joint R&D and patent application has become a common strategy due to the difficulty and low success rate. Governments of various countries have developed and implemented a range of measures regarding the application and protection of COVID-19 related patents. Patents have become an effective tool in the fight against COVID-19. In this context, China should pay attention to the R&D and joint patent application of COVID-19 products, so as to enhance the global confidence and ability to fight against COVID-19.

A literature review on patent cooperation reveals that numerous studies have been undertaken in terms of different disciplines and perspectives to analyze the structure, characteristics, geographical distribution, technical field distribution, and evolution, etc. of the patent cooperation network using social network analysis and other tools based on world-renowned patent databases. Ejermo and Karlsson (1) believe that the patent cooperation network often causes agglomeration, and that geographical distance has a great impact on the degree of agglomeration of the cooperation network. Schilling and Phelps (2) found that patent cooperation networks with high aggregation and short average path have stronger innovation capabilities. Fleming et al. (3) found that interregional patent cooperation networks have obvious small-world characteristics, and that patent cooperation has multiple benefits. A study of top 10 innovative countries by Ma and Lee (4) suggests that the state's support for scientific research enhances patent cooperation, whether domestically or internationally. Based on practical research in Sweden, Wilhelmsson (5) believes that patent cooperation networks mainly occur in cities with a large population and diversified industries, but the market size has a negative impact on the network, and the degree of patent cooperation in large cities is relatively low. Graf and Henning (6) found that universities and research institutes occupy an important position in the patent cooperation network constructed by cities in northeastern Germany. Goetze (7) believes that the personal network of patent inventors has a positive impact on the number of patents. Lissoni (8) found that universities that cooperate with enterprises to apply for patents are more likely to occupy the core position of university inventor cooperation networks. From the perspective of patent cooperation, Carrillo et al. (9) found that universities play the role of gatekeepers in R&D cooperation networks. Petruzzelli (10) suggests that the strength of patent cooperation between European universities and enterprises has a strong relationship with the distance between them and whether they have cooperated before. Wanzenböck and Heller-Schuh (11) analyzed the regional dynamic evolution of co-authored papers and co-patent data in Europe, and found that there are gaps in the status and power of each European region in the knowledge transfer network. Barber and Scherngell (12) found that the spatial evolution of the European patent cooperation network is heterogeneous. Lee (13) reported that the complexity of the US intercity network continued to expand and deepen during 1979–2009, and that co-invention was closely related to core urban areas. Sun et al. (14) found that the patent cooperation activities of patent applicants tend to be more frequent in the patent cooperation network in the field of new energy vehicles in China.

Research on innovation cooperation networks in the field of public health can be divided into two perspectives, which are regional and global. For example, regional research investigated innovation cooperation networks for tropical diseases, such as malaria, dengue fever, and leprosy, in Brazil (15), public health in Colombia (16), biotechnology in northeastern Brazil (17), tropical diseases in Germany (18), and health care among Spanish universities (19) to provide information for the strategic planning of health organizations in the respective regions. Global research mainly examined global research cooperation networks for a specific disease, drug, and biotechnology. For example, González-Alcaide et al. (20) analyzed the global research cooperation network for leishmaniasis to identify the roles of key countries and persons in the network. In addition, a study reviewed more than 3,000 co-authored papers on health management included in the Web of Science database in the past 13 years to identify key researchers and institutions in the cooperation networks of public health research, as well as their roles in information dissemination and health management (21). All the above studies on innovation cooperation networks in the field of public health use co-authored papers as data. When using patent data, regional studies investigated biotechnology cooperation in Brazil (22), tuberculosis prevention and treatment in Brazil (23), collaborative innovation in Chinese medicine (24), the impact of patent cooperation on firm patent output in the pharmaceutical industry in Beijing-Tianjin-Hebei region in China (25), and the impact of patent cooperation network on small and medium-sized enterprises in the pharmaceutical industry of China[1], etc., thereby providing guidance for decision-making on regional public health development. On a global scale, Liu et al. (26) investigated the global landscape of patents related to

1 https://xs.dailyheadlines.cc/scholar?start=10&q=medicine$+$Patent$+$Cooperation$+$Network&hl=zh-CN&as_sdt=0,5#:$\sim$:text$=$Wang%20L%2C%20Wang%20J%2C%20Yu%20W.%20The%20influence%20of%20patent%20cooperation%20network%20on%20growth%20of%20technology%2Dbased%20SMEs%3A%20an%20example%20of%20the%20pharmaceutical%20industry%20in%20China%5BM%5D//Innovative%20Capabilities%20and%20the%20Globalization%20of%20Chinese%20Firms.%20Edward%20Elgar%20Publishing%2C%202020

human coronaviruses; and Zhu and Gao (27) analyzed the global biopharmaceutical patent cooperation network using a clustering comparison approach, and identified cross-border regional collaborative centers.

At present, studies on COVID-19 innovation networks mostly used co-authored papers as data sources. For example, Patil (28), Lee and Haupt (29), Yamin et al. (30), and Thavorn et al. (31) conducted bibliometric analyses of COVID-19 innovation networks based on co-authored papers and publications retrieved by the keyword "COVID-19". However, there are few studies that examine COVID-19 innovation cooperation networks using patent data. The study by Liu et al. (26) mentioned above analyzed the global cooperation network of coronavirus patents. In particular, it not only analyzed the COVID-19 patent data, but also examined the patent data of the other six coronaviruses. Yamin et al. (30) analyzed the innovation networks in the field of emergency drugs using the patent data of COVID-19 drugs and determined its structural evolution and policy impact. Meanwhile, research on COVID-19 patent cooperation networks in China mainly focuses on drug combinations and is applied to patent design and intellectual property application (32–34). However, there are few studies that analyze network structure at the province (municipality), city, and applicant levels.

A literature review reveals that patent cooperation for COVID-19 has not been widely studied, and the structural characteristics of the COVID-19 patent cooperation network in China are more rarely analyzed. Therefore, the contribution of this paper is to explore the spatial characteristics of the fight against COVID-19 in China at the province, city, and applicant levels based on COVID-19 patent cooperation data, which will enable identification of problems from a new perspective and help to clarify the current technology accumulation in this field in China and propose optimization strategies for the COVID-19 patent cooperation network. From a practical point of view, it will hopefully provide patent information support for the scientific efforts to fight against COVID-19, such as prevention and treatment, vaccine development, and clinical drug screening. It also provides a theoretical basis for patented technology development strategies, and contributes to rethinking the geography of innovation.

Data and methods

Data

The data are from the Incopat global patent database. Patents with two or more applicants were retrieved from the Incopat database using keywords related to COVID-19 in the patent abstracts. The retrieval formula was as follows:

(TIAB = (xin-guan [Chinese name of COVID-19] OR xin-guan-bing-du [Chinese name of COVID-19 virus] OR xin-xing-guan-zhuang-bing-du [another Chinese name of COVID-19 virus] OR xin-xing-guan-zhuang-bing-du-fei-yan [Chinese name of Coronavirus Disease 2019] OR 2019-nCoV OR guan-zhuang-bing-du [Chinese name of coronavirus] OR SARS-CoV-2)) NOT [NO-AP = (1)].

A total of 650 COVID-19 patents were identified within the years 2020, 2021, and 2022 In the calculation of patent cooperation, for example, if a patent was applied for by three applicants A, B, and C, one cooperation between A and B, A and C, and B and C, respectively, was identified.

The retrieval was performed on April 20, 2022. Finally, a 27×27 matrix was formed for the inter-provincial cooperation network, and an 83×83 matrix for the inter-city cooperation network. For the applicant cooperation network, only patent applicants who cooperated more than five times were included, and finally a 75×75 matrix was formed from 696 applicants.

Three types of patent applicants are identified, which are firms, universities, and research institutes. In particular, university hospitals are identified as universities because they undertake both talent training and research. Other hospitals are identified as research institutes as they focus on research.

Methods

The COVID-19 patent cooperation network was characterized by changes in centrality, betweenness centrality, closeness centrality, structural holes, and cohesive subgroups revealed by social network analysis.

Centrality

It is the main measure of the control power of nodes in the whole network (Equation 1). Normalized centrality is often used to eliminate the influence of the total number of nodes.

$$C_D(n_i) = d(n_i) = \sum_j X_{ij} = \sum_i X_{ji} \quad (1)$$

where $C_D(n_i)$ is the absolute centrality of node i. X_{ij} and X_{ji} are 0 or 1, indicating whether there is a relationship between nodes i and j.

Closeness centrality

It measures how close a node is to all other nodes, reflecting its control over other nodes.

$$CC_i = (g-1)/\sum_{j=1, j\neq i}^{N} d_{ij} \quad (2)$$

where g is the number of network nodes. d_{ij} is the number of steps in the shortest path between nodes i and j.

Betweenness centrality

It measures the degree to which a node is located in the "middle" of other nodes, thus reflecting a state's ability to control the channels and mediate the flow of energy in the network. Assuming that the number of shortest paths between nodes j and k is g_{jk}, and the number of shortest paths between nodes j and k passing through node i is $g_{\mathrm{jk}}(i)$, the ability of node i to control the association between nodes j and k can be defined as $b_{jk}(i) = \frac{g_{jk}(i)}{g_{jk}}$.

$$BC_i = \frac{2\sum_{j}^{n}\sum_{k}^{n} b_{jk}(i)}{N^2 - 3N + 2}(j \neq k \neq i) \quad (3)$$

Structural holes

Effective size, efficiency, constraint, and hierarchy are the measures of structural holes. Among them, constraint is the most important measure. Therefore, only the constraint of structural holes was analyzed in this study. The operational definition of constraint is that actor i is indexed by the constraint of j.

$$C_{ij} = \left(p_{ij} + \sum_{q} p_{iq}p_{qj}\right)^2 \quad (4)$$

It can be expressed as $C_{ij} = direct\ input\ (p_{ij}) + indirect\ input\ (\sum_q p_{iq}p_{qj})$. Where p_{iq} is the proportion of relationships involved in q in the total relationships of actor i.

Cohesive subgroups

The block model approach is a way of partitioning nodes by structural information. Cohesive subgroup analysis is generally performed by convergence of iterated correlation (CONCOR). Cohesive subgroups can be used to investigate the internal association and grouping of nodes in the network.

Topological features of China's COVID-19 patent network

Cooperation level

The COVID-19 patent cooperation networks at the province, city, and applicant levels within China were constructed. Results are shown in Figure 1 and Table 1.

In terms of inter-provincial cooperation, there are a total of 85 pairs of provinces/municipalities in the network. The highest cooperation level is found for Beijing–Jiangsu, which is 23, and the lowest is 1. Only 11.76% of them have a cooperation level of 10 and above, and 27.05% have a cooperation level of 5 and above. Specifically, Beijing–Jiangsu, Jiangsu–Shanghai, and Guangdong–Shanghai have the highest cooperation level of more than 20. Beijing–Liaoning, Tianjin–Chongqing, Zhejiang–Beijing, Guangdong–Jiangsu, Beijing–Guangdong, Beijing–Tianjin, and Shanghai–Hubei have the second highest cooperation level of 10 and above. Hubei–Guangdong, Beijing–Shanghai, Beijing–Shaanxi, and Sichuan–Beijing have the third highest cooperation level of 7 to 9. The remaining pairs of provinces/municipalities have a low cooperation level of below 7. In terms of eastern, central, and western provinces, the highest cooperation level is observed between eastern provinces, which is much higher than the second and third highest cooperation level that is observed between eastern and central provinces and between eastern and western provinces, respectively.

In terms of inter-city cooperation, there are 166 city pairs in the network. The highest cooperation level is found for Suzhou–Shanghai, which is 17, and the lowest is 1. Only 5.42% of them have a cooperation level of 10 and above, and 12.65% have a cooperation level of 5 and above. Specifically, Suzhou–Shanghai, Tianjin–Chongqing, and Guangzhou–Shenzhen have the highest cooperation level of more than 15. Beijing–Shenyang, Shanghai–Wuhan, Hangzhou–Beijing, Nanjing–Beijing, Beijing–Tianjin, and Guangzhou–Shanghai have the second highest cooperation level of 10 and above. Guangzhou–Chaozhou, Beijing–Suzhou, Shanghai–Shenzhen, Beijing–Shenzhen, Beijing–Xianyang, and Chengdu–Beijing have the third highest cooperation level of 7–9. The remaining pairs of cities have a low cooperation level of below 7. In terms of provincial capital and non-provincial capital cities, the lowest cooperation level is observed between non-provincial capital cities, and the highest is between provincial capital and non-provincial capital cities.

In terms of applicant cooperation, there are a total of 133 pairs of applicants in the network. The highest cooperation level is observed between Bioscience (Tianjin) Diagnostic Technology Co., Ltd.–Chongqing Medical University, which is 17, and the lowest is 1. There are only 2 pairs of applicants with a cooperation level of 10 and above, and 15 pairs with a cooperation level of 5 and above. Specifically, Bioscience (Tianjin) Diagnostic Technology Co., Ltd.–Chongqing Medical University and Tsinghua University–Liaoning Chengda Biotechnology Co., Ltd. have the highest cooperation level of more than 10. Suzhou Genepharma Co., Ltd.–Shanghai GenePharma Co., Ltd., Guangzhou Vision Gene Tech Co., Ltd.–Guangzhou Vision Medical Laboratory Co., Ltd., Guangzhou Vision Gene Tech Co., Ltd.–Shenzhen Vision Medical Tech Co., Ltd., Guangzhou Vision Medical Equipment Co., Ltd.–Guangzhou Vision Medical Laboratory Co., Ltd., Guangzhou Vision Medical Equipment Co., Ltd.–Shenzhen Vision Medical Tech Co., Ltd., and Guangzhou Vision Medical Laboratory Co., Ltd.–Shenzhen Vision Medical Tech Co., Ltd. have the

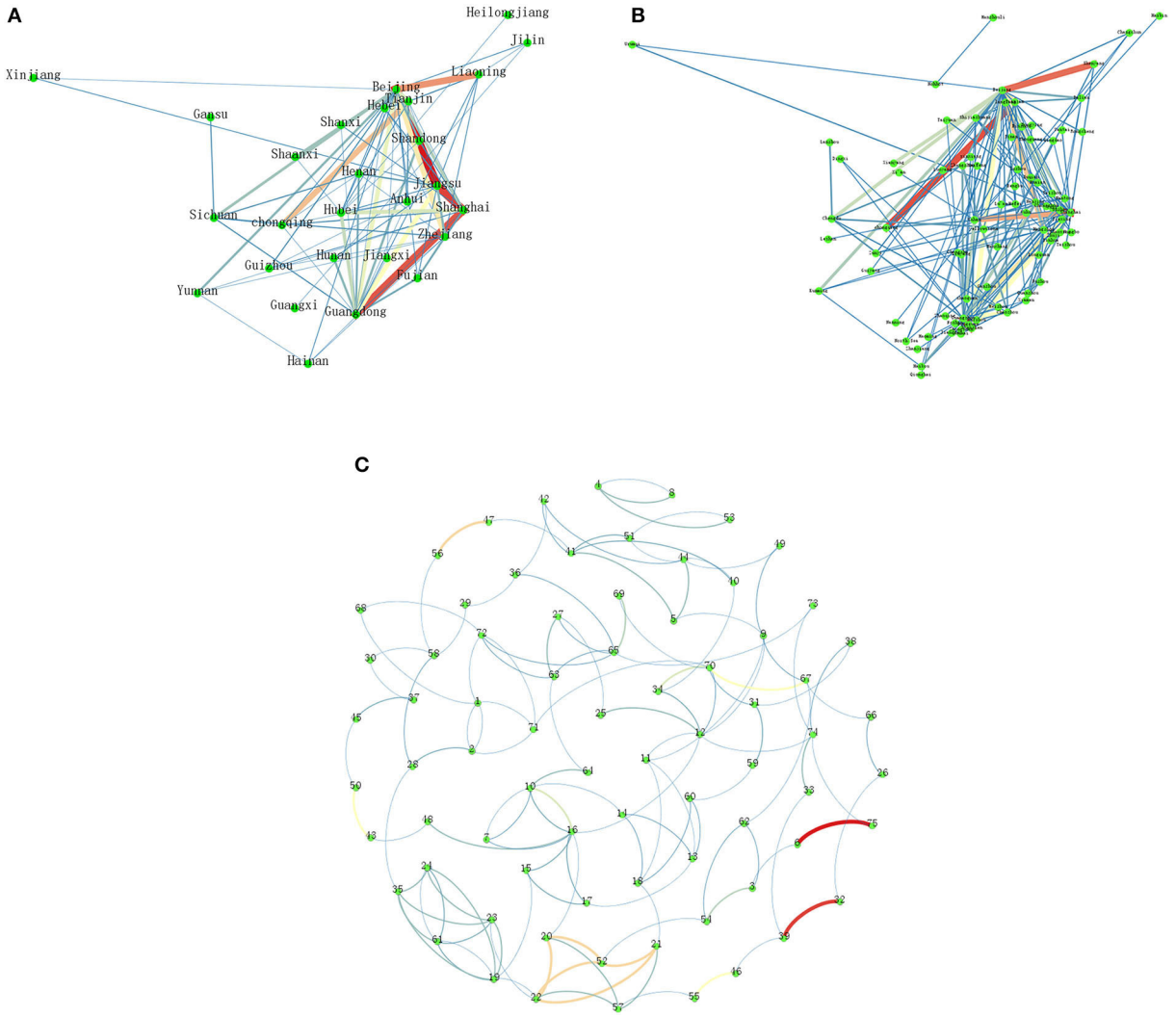


FIGURE 1
COVID-19 patent cooperation networks. **(A)** Inter-provincial COVID-19 patent cooperation network. **(B)** Inter-city COVID-19 patent cooperation network. **(C)** Inter-applicant COVID-19 patent cooperation network. Line thickness and red–yellow–green colors represent the level of cooperation. 1: Peking University; 2: Beijing University of Chemical Technology; 3: Beijing Institute of Hepatology; 4: Beijing Zhituo Vision Technology Co., Ltd.; 5: Affiliated Hospital of Binzhou Medical College; 6: Bioscience (Tianjin) Diagnostic Technology Co., Ltd.; 7: Chaozhou Kaipu Biochemical Co., Ltd.; 8: Dalian University of Technology; 9: Fudan University; 10: Guangdong Hybribio Biotech Co., Ltd.; 11: Guangzhou National Laboratory; 12: Guangzhou Institute of Respiratory Health; 13: Guangzhou Kingmed Diagnostics Group Co., Ltd.; 14: Guangzhou Kingmed Center for Clinical Laboratory Co., Ltd.; 15: Guangzhou Kaipu Biotechnology Co., Ltd.; 16: Guangzhou Kaipu Pharmaceutical Technology Co., Ltd.; 17: Guangzhou Kangjian Medical Technology Co., Ltd.; 18: Guangzhou Kingmed Translational Medicine Research Institute Co., Ltd.; 19: Guangzhou Welman New Drug R&D Co., Ltd.; 20: Guangzhou Vision Gene Tech Co., Ltd.; 21: Guangzhou Vision Medical Equipment Co., Ltd.; 22: Guangzhou Vision Medical Laboratory Co., Ltd.; 23: Guangzhou Century Clinical Research Co., Ltd.; 24: Guangzhou Xin-Chuangyi Biopharmaceutical Co., Ltd.; 25: The First Affiliated Hospital of Guangzhou Medical University (Guangzhou Respiratory Center); 26: Guangzhou Laboratory of Regenerative Medicine and Health Guangdong Province; 27: Hangzhou Medical College; 28: North China Pharmaceutical Group New Drug R&D Co., Ltd.; 29: East China University of Science and Technology; 30: Huazhong University of Science and Technology; 31: Huazhong Agricultural University; 32: Liaoning Chengda Biotechnology Co., Ltd.; 33: Southern University of Science and Technology; 34: Southern Medical University; 35: Nanjing Kangfushun Pharmaceutical Co., Ltd.; 36: Nankai University; 37: Qilu University of Technology; 38: Qingdao Marine Biomedical Research Institute Co., Ltd.; 39: Tsinghua University; 40: Qingyuan Biotechnology (Jiangsu) Co., Ltd.; 41: Qingyuan Biotechnology (Shenzhen) Co., Ltd.; 42: Qingyuanzhiguang (Wuhan) Biotechnology Co., Ltd.; 43: Sanyou Biopharmaceuticals (Shanghai) Co., Ltd.; 44: Shandong Binzhou Academy of Animal Science and Veterinary Medicine Academy Academy; 45: Shandong Modern Chinese Medicine Research Institute Co., Ltd.; 46: Affiliated Hospital of Shaanxi University of Traditional Chinese Medicine; 47: Shanghai GenePharma Co., Ltd.; 48: Shanghai Kaipu Medical Laboratory Co., Ltd.; 49: Shanghai Fosun Med-Tech Development Co., Ltd.; 50: Shanghai ZJ Bio-Tech Co., Ltd.; 51: Shenzhen Mingde Biotechnology Co., Ltd.; 52: Shenzhen Vision Medical Tech Co., Ltd.; 53: Beijing Friendship Hospital Affiliated to Capital Medical University; 54: Beijing Youan Hospital, Capital Medical AL University; 55: Beijing Hospital of Traditional Chinese Medicine Affiliated to Capital Medical University; 56: Suzhou Genepharma Co., Ltd.; 57: Vision (Shenzhen) Medical Research Center Co., Ltd.; 58: Wuhan University; 59: Wuhan Keqian Biology Co., Ltd.; 60: City University of Hong Kong Shenzhen Research Institute;
(Continued)

FIGURE 1 (Continued)
61: Xiangbei Welman Pharmaceutical Co., Ltd.; 62: The First Affiliated Hospital, Zhejiang University School of Medicine; 63: Zhejiang Pukang Biotechnology Co., Ltd.; 64: Zhengzhou Kaipu Medical Laboratory (Limited Partnership); 65: National Institute for Viral Disease Control and Prevention, China CDC; 66: Guangzhou Institute of Biomedicine and Health, Chinese Academy of Sciences; 67: Shanghai Institute of Materia Medica, Chinese Academy of Sciences; 68: Institute of Biophysics, Chinese Academy of Sciences; 69: Institute of Microbiology, Chinese Academy of Sciences; 70: Wuhan Institute of Virology, Chinese Academy of Sciences; 71: Academy of Military Medicine, Academy of Military Sciences, Chinese People's Liberation Army; 72: Institute of Laboratory Animals Science, CAMS & PUMC; 73: Wuxi Customs, People's Republic of China; 74: Sun Yat-Sen University; 75: Chongqing Medical University.

TABLE 1 Types and levels of COVID-19 patent cooperation.

Level	Cooperation type		Cooperation level
Province	Eastern province	Eastern province	180
	Eastern province	Central province	86
	Eastern province	Western province	60
	Western province	Central province	7
	Central province	Central province	5
	Western province	Western province	4
City	Non-provincial capital city	Provincial capital city	221
	Provincial capital city	Provincial capital city	201
	Non-provincial capital city	Non-provincial capital city	34
Applicant	Firm	Firm	144
	University	Firm	52
	University	Research institute	33
	Research institute	Research institute	26
	Firm	Research institute	23
	University	University	16

second highest cooperation level of 8 and above. Beijing Hospital of Traditional Chinese Medicine Affiliated to Capital Medical University–Affiliated Hospital of Shaanxi University of Traditional Chinese Medicine, Sanyou Biopharmaceuticals Co., Ltd.–Shanghai ZJ Bio-Tech Co., Ltd., Shanghai Institute of Materia Medica, Chinese Academy of Sciences–Wuhan Institute of Virology, Chinese Academy of Sciences, Southern Medical University–Wuhan Institute of Virology, Chinese Academy of Sciences, Guangdong Hybribio Biotech Co., Ltd.–Guangzhou Technology Ltd., Institute of Microbiology, Chinese Academy of Sciences–National Institute for Viral Disease Control and Prevention, China CDC, and Beijing Youan Hospital, Capital Medical AL University–Beijing Institute of Hepatology have the third highest cooperation level of 5 to 7. The remaining pairs of patent applicants have a low cooperation level of below 5. In terms of the types of patent applicants, the highest cooperation level is observed between firms, which is 144, nearly three times of the second highest level that is observed between universities and firms; and the lowest cooperation level is observed between universities.

The cooperation networks between provinces and cities are mainly formed through hierarchical and contagious diffusion. The cooperation between patent applicants is mainly based on kinship and business, supplemented by geographical proximity. As can be seen from Figure 2, China's COVID-19 patent cooperation network roughly has a structure centered on the Beijing-Tianjin-Hebei Region, Yangtze River Delta, and Pearl River Delta. It suggests that the three major urban agglomerations have a high integration of the COVID-19 industry, and have high cooperation between provinces and cities. There are also some nodes in the northeastern and western regions. The north–south cooperation is stronger higher than the east–west cooperation. Developed provinces and cities have close cooperation with each other. For example, Beijing–Jiangsu, Jiangsu–Shanghai, Guangdong–Shanghai, Suzhou–Shanghai, Tianjin–Chongqing, and Guangzhou–Shenzhen have a cooperation level of more than 15. In addition, provinces and cities in close proximity also have a high level of cooperation. For example, Jiangsu–Shanghai and Suzhou–Shanghai have a cooperation level of more than 15. It suggests that geographical proximity enables convenient communication and management, which has a great impact on COVID-19 patent cooperation. Among patent applicants with a relatively high cooperation level, a business-based cooperation model between applicants

with similar or the same business scope is noted at the highest level, a kinship-based cooperation model between applicants in investment relationships at the second highest level, and a business-based cooperation model again at the third highest level. However, most patent applicants are also located relatively close together in these two main cooperation models.

On the whole, the inter-regional cooperation level in China's COVID-19 patent cooperation network shows a decreasing trend from eastern to central to western regions. Eastern provinces and cities have stable partners; collaborative innovation in central provinces and cities need to be further improved; whereas there is still a lot of room for development in the western provinces and cities in establishing patent cooperation with other regions. At the applicant level, kinship-based cooperation is the strongest, business-based cooperation has the widest scope, while proximity-based cooperation exists throughout these two main models of cooperation.

Centrality

Node centrality measures the number of nodes directly connected to a given node, reflecting the importance of that role in the network. Intuitively, a node directly connected to many nodes has a high degree centrality, which reflects its relative importance in China's COVID-19 patent cooperation network.

As shown in Table 2, in terms of inter-provincial cooperation, Beijing has the highest centrality, indicating that it occupies a central position in the network and has a strong influence on other provinces in the entire network. The other provinces, such as Guangdong, Shanghai, and Jiangsu, have similar centrality in the network, while Yunnan, Anhui, and Hunan are at the edge. In terms of inter-city cooperation, Beijing still has the highest centrality, which is far higher than the second highest centrality of Guangzhou. It indicates that Beijing has an absolutely core influence in the entire network. It carried out 111 patent cooperation activities with other cities, far exceeding that by other cities. In terms of inter-applicant cooperation, most of the top 20 applicants are firms, and the top four applicants are Vision and its subsidiaries. Specifically, Guangzhou Vision Medical Laboratory Co., Ltd. had the most relations and carried out 28 patent cooperation activities with other entities. Among the research institutes, Wuhan Institute of Virology, Chinese Academy of Sciences has the largest centrality of 17. Among the universities, Chongqing Medical University has the largest centrality. It indicates that these patent applicants have the largest number of cooperators, form a large patent cooperation network by themselves, and have access to abundant resources. Compared with other nodes, they are more embedded and occupy an important position in the network, and have a greater influence.

Betweenness centrality

Betweenness centrality measures whether a node occupies an intermediate position between other nodes. The higher the betweenness centrality, the stronger its control over the path. It reflects the degree of control this node has over resources, that is, the degree to which it acts as a bridge (i.e., a line of communication between nodes). As shown in Table 3, Beijing ranks first in terms of betweenness centrality at both province and city levels, being much higher than the second highest ones. It indicates that Beijing has absolute control over the path of the COVID-19 patent cooperation network, occupies a pivotal position in this network, and plays a significant bridging role in the cooperation. At the province level, cooperation in the network mainly occurs through Beijing, Guangdong, Hubei, and Shanghai. At the city level, cooperation mainly occurs through Beijing, Guangzhou, Shanghai, and Shenzhen. At the applicant level, cooperation mainly occurs through Guangzhou Institute of Respiratory Health, Guangzhou National Laboratory, Wuhan Institute of Virology, Chinese Academy of Sciences, Shanghai Institute of Materia Medica, Chinese Academy of Sciences, and Peking University. It indicates that these institutes or universities have relatively more information on COVID-19, and have control over the path of the COVID-19 patent cooperation network.

Closeness centrality

Closeness centrality measures how close a given node is to other nodes in the network. It is defined as the reciprocal of the sum of the shortest path distances from that node to all other nodes. The closer a node is to other nodes, the greater its closeness centrality. The shorter the sum of the shortest paths from a node to all other nodes, the easier it is for information resources in the network to reach this node.

As shown in Table 4, at the province level, coastal provinces/municipalities, such as Beijing, Guangdong, Shanghai, Jiangsu, and Zhejiang, have higher closeness centrality. At the city level, coastal cities, such as Beijing, Guangzhou, Shanghai, Nanjing, and Shenzhen, rank high in closeness centrality. At the applicant level, universities and research institutes, such as Guangzhou Institute of Respiratory Health, Wuhan Institute of Virology, Chinese Academy of Sciences, Fudan University, Guangzhou National Laboratory, and Southern Medical University, have higher closeness centrality, occupying a prominent position in the network. It suggests that these nodes are closer to other innovative

entities in China's COVID-19 patent cooperation network. The shorter path length also enables these nodes to acquire network resources or search for partners in a shorter time and with higher efficiency than other nodes.

Structural holes

Structural holes are often used to reveal the degree of homogeneous competition among nodes in a patent cooperation network. Effective size, efficiency, and constraint were calculated using UCINET. Among them, efficiency and constraint are the two most important measures. A node with higher efficiency and smaller constraint has greater structural holes and obvious advantages. As shown in Table 5, at the province level, Beijing, Guangdong, Shanghai, Jiangsu, Hubei, Zhejiang, and Tianjin have a significantly larger effective size and efficiency and smaller constraint than other provinces/municipalities. It indicates that these provinces/municipalities are less constrained by others, have more opportunities for competition, and have significant advantages of structural holes. At the city level, Beijing, Guangzhou, Shanghai, Shenzhen, Nanjing, and Hangzhou have a relatively larger effective size and efficiency and smaller constraint. It indicates that these cities are less constrained by other cities and occupy the position of structural holes in the network. At the applicant level, research institutes and firms make greater use of structural holes. Specifically, Guangzhou Institute of Respiratory Health, National Institute for Viral Disease Control and Prevention, China CDC, Guangzhou Technology Ltd., Shandong Binzhou Academy of Animal Science and Veterinary Medicine Academy, and Qingyuan Biotechnology (Shenzhen) Co., Ltd. occupy the position of structural holes, have significant competitive advantages, and are less constrained by other applicants.

Cohesive subgroups

Cohesive subgroups are used to analyze the cliques in a group network and clique composition by quantifying group cohesiveness, thereby describing the group relationships. The external-internal (E-I) index is used to measure the dominance of external relations over internal relations, and analyze the relationships between and within subgroups in network structure analysis. It is calculated as follows:

$$E - I = \frac{EL - IL}{EL + IL} \tag{5}$$

where EL is the number of relationships between subgroups, and IL is the number of relationships within subgroups. The value range of the E-I index is [−1, +1]. The closer the value is to 1,

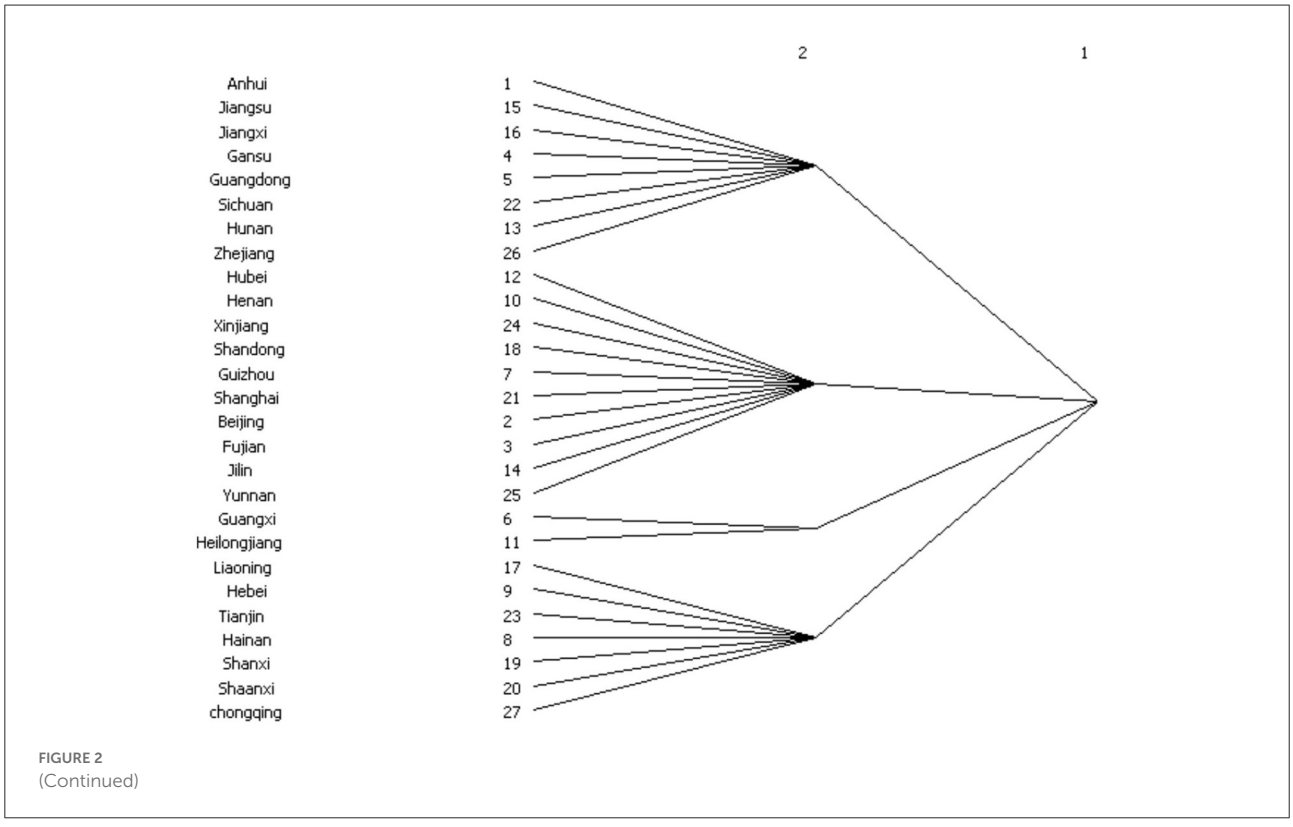


FIGURE 2
(Continued)

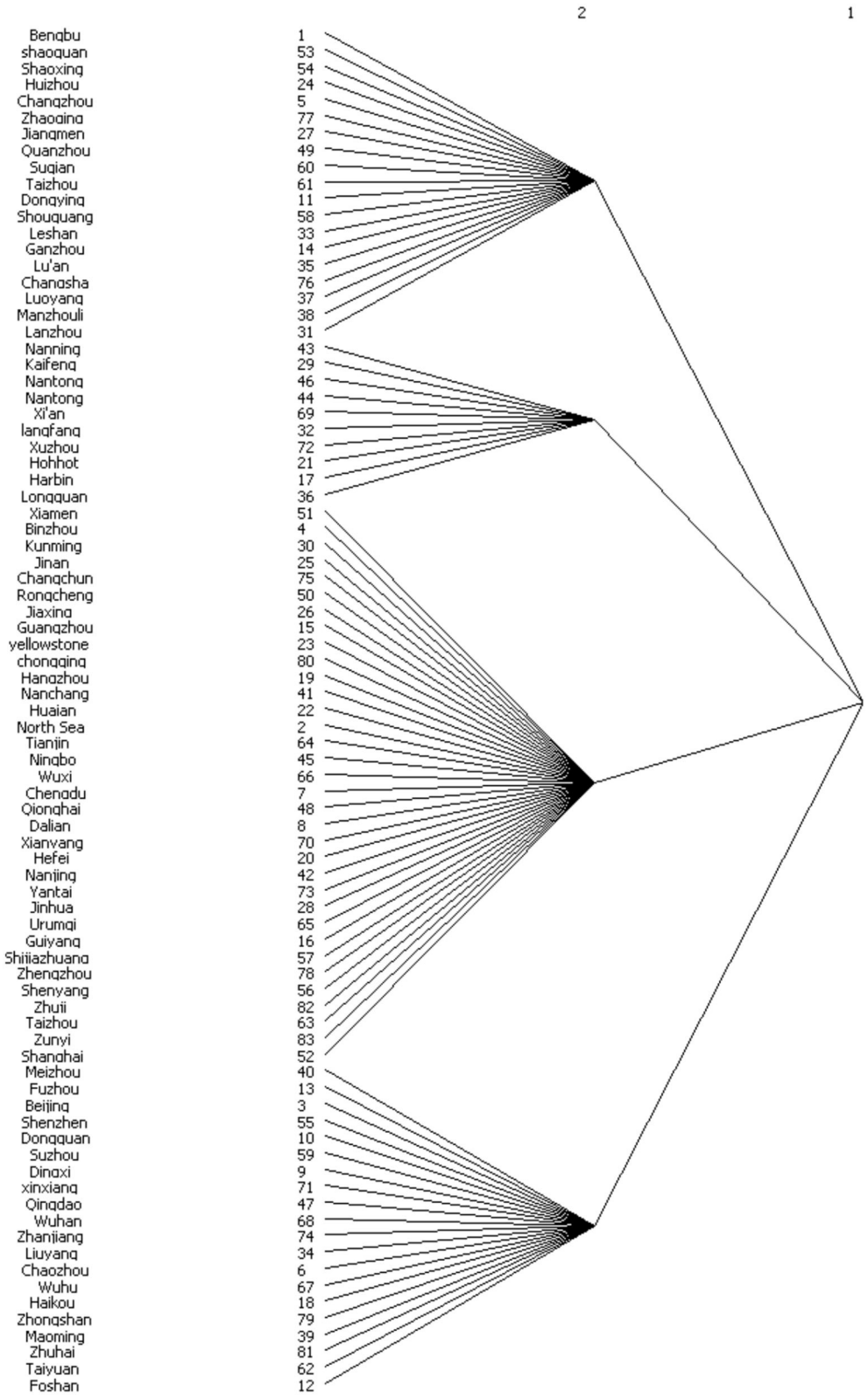


FIGURE 2
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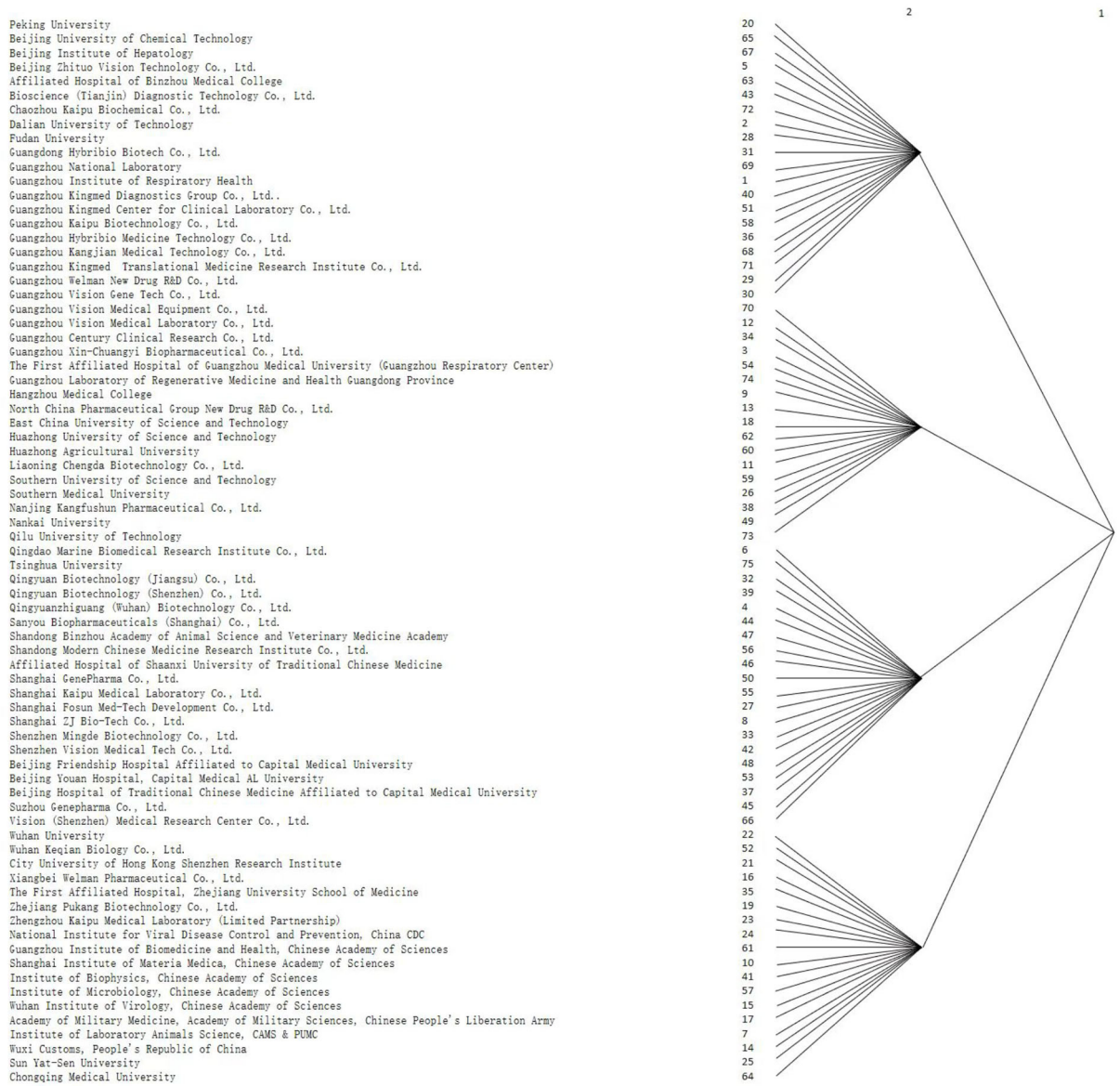


FIGURE 2
Cohesive subgroups in the COVID-19 patent cooperation networks.

the more likely the relationships occur outside the subgroups, and the smaller the number of cliques On the contrary, the closer the value is to −1, the more likely the relationships occur within the subgroups, and the larger the number of cliques. A value equal to 0 indicates that the relationships in the network are randomly distributed.

The cohesive subgroups of the COVID-19 patent cooperation network were analyzed using UCINET (Figure 2). There are four subgroups in the COVID-19 patent cooperation network at the province, city, and applicant levels, respectively. As revealed by the macro structure of the network and the E-I index analysis results in Table 6, at the provincial level, the first subgroup is centered on Guangdong and Jiangsu and radiated to Anhui, Jiangxi and other provinces; the second subgroup is centered on Beijing and Shanghai and extended to Hubei, Henan, Xinjiang and other provinces; the third subgroup consists of Guangxi and Heilongjiang; and the fourth subgroup is centered on Tianjin and extended to Hainan, Shanxi, Shaanxi and other provinces.

At the city level, the first subgroup consists of Bengbu, Changzhou, Dongying, Ganzhou and other cities; the second subgroup consists of Harbin, Hohhot,

10.3389/fpubh.2022.985576

TABLE 2 Centrality of top 20 nodes in the COVID-19 patent cooperation network.

Province/ municipality	Centrality	City	Centrality	Applicant	Centrality
Beijing	93	Beijing	111	Guangzhou Vision Medical Laboratory Co., Ltd.	28
Guangdong	65	Guangzhou	75	Shenzhen Vision Medical Tech Co., Ltd.	24
Shanghai	60	Shanghai	66	Guangzhou Vision Medical Equipment Co., Ltd.	20
Jiangsu	55	Shenzhen	46	Guangzhou Vision Gene Tech Co., Ltd.	20
Zhejiang	36	Nanjing	36	Guangzhou Technology Ltd.	18
Tianjin	29	Wuhan	32	Wuhan Institute of Virology, Chinese Academy of Sciences	17
Hubei	29	Tianjin	32	Nanjing Kangfushun Pharmaceutical Co., Ltd.	16
Liaoning	23	Hangzhou	29	Guangzhou Welman New Drug R&D Co Ltd.	15
Chongqing	22	Suzhou	25	Guangzhou Century Clinical Research Co., Ltd.	15
Sichuan	16	Chongqing	21	Guangzhou Xin-Chuangyi Biopharmaceutical Co., Ltd.	15
Henan	15	Chengdu	18	National Institute for Viral Disease Control and Prevention, China CDC	14
Fujian	15	Shenyang	17	Bioscience (Tianjin) Diagnostic Technology Co., Ltd.	13
Hebei	13	Chaozhou	17	Chongqing Medical University	13
Shandong	12	Zhengzhou	15	Xiangbei Welman Pharmaceutical Co., Ltd.	13
Yunnan	9	Shijiazhuang	15	Qingyuan Biotechnology (Shenzhen) Co., Ltd.	12
Anhui	8	Xiamen	14	Liaoning Chengda Biotechnology Co., Ltd.	12
Shaanxi	8	Kunming	9	Vision (Shenzhen) Medical Research Center Co., Ltd.	12
Hunan	7	Fuzhou	8	Guangzhou Institute of Respiratory Health	12
Guizhou	6	Haikou	8	Tsinghua University	12
Hainan	5	Hefei	8	Guangdong Hybribio Biotech Co., Ltd.	12

Kaifeng, Langfang and other cities; the third subgroup is centered on Guangzhou and Shanghai, and radiated to Nanchang, Nanjing, Ningbo, Xiamen and other cities; and the fourth subgroup is centered on Beijing and extended to Chaozhou, Dingxi, Dongguan, Foshan and other cities.

At the applicant level, the first subgroup is centered on Guangzhou Vision Gene Tech Co., Ltd. and radiated to Peking University, Beijing University of Chemical Technology and other applicants; the second subgroup is centered on the Wuhan Institute of Virology, Chinese Academy of Sciences and extended to Beijing Institute of Hepatology, Fudan University and other applicants; the third subgroup is centered on Bioscience (Tianjin) Diagnostic Technology Co., Ltd. and Chongqing Medical University, and extended to Dalian University of Technology, Hangzhou Medical College and other applicants; and the fourth subgroup is centered on Guangzhou Vision Medical Laboratory Co., Ltd. and Shenzhen Vision Medical Tech Co., Ltd., and extended to Guangzhou Vision Medical Equipment Co., Ltd., Guangzhou Technology Ltd. and other applicants.

At the province and city levels, the E-I indices is positive for all subgroups. The number of external relationships of subgroup nodes is significantly greater than that of internal relationships. There is no large number of cliques, indicating a great potential for development. Nodes in the third subgroup in the inter-provincial cooperation network and the second subgroup in the inter-city cooperation network are relatively dispersive, have weak cooperation relations, and are less involved in the COVID-19 patent cooperation with other nodes. These nodes have strong external relationships. Their level of patent cooperation lags behind the overall average. They are at the edge of the COVID-19 patent cooperation network. At the applicant level, the E-I index is negative for all subgroups. The number of external relationships of subgroup nodes is significantly smaller than that of internal relationships, indicating a tendency of clique formation. Cooperation in the first to third subgroups is mainly based on business and geographical proximity, and that in the fourth subgroup is based on kinship and geographical proximity. These subgroup cooperation models hinder the flow of resources and factors within the subgroups and reduce the efficiency of patent cooperation and communication. To avoid a great number of cliques and consequent information barriers, which would restrict the overall development of the subgroups, subgroups nodes in the patent applicant cooperation should strengthen communication with external nodes and develop a diversified patent cooperation network.

TABLE 3 Betweenness centrality of top 20 nodes in the COVID-19 patent cooperation network.

Province/ municipality	Betweenness centrality	City	Betweenness centrality	Applicant	Betweenness centrality
Beijing	36.813	Beijing	40.011	Guangzhou Institute of Respiratory Health	4.369
Guangdong	15.226	Guangzhou	22.727	Guangzhou National Laboratory	2.234
Hubei	10.213	Shanghai	11.853	Wuhan Institute of Virology, Chinese Academy of Sciences	2.147
Shanghai	8.233	Shenzhen	10.362	Wuhan Institute of Virology, Chinese Academy of Sciences	1.888
Sichuan	7.754	Nanjing	8.785	Peking University	1.777
Jilin	7.692	Hangzhou	8.293	Institute of Laboratory Animals Science, CAMS & PUMC	1.777
Jiangsu	6.885	Wuhan	6.395	National Institute for Viral Disease Control and Prevention, China CDC	1.499
Zhejiang	4.656	Hefei	4.487	Beijing University of Chemical Technology	1.481
Liaoning	1.844	Chongqing	3.267	Fudan University	1.407
Chongqing	0.972	Tianjin	2.878	Sun Yat-sen University	1.296
Tianjin	0.938	Shijiazhuang	2.481	The First Affiliated Hospital, Zhejiang University School of Medicine	1.259
Henan	0.892	Chengdu	2.359	North China Pharmaceutical Group New Drug R&D Co., Ltd.	1.222
Hebei	0.203	Chaozhou	2.326	Wuhan University	0.926
Anhui	0.141	Shenyang	2.258	Huazhong Agricultural University	0.666
Fujian	0.000	Jiaxing	2.258	Guangzhou Kingmed Diagnostics Group Co., Ltd.	0.611
Shandong	0.000	Changchun	2.258	Guangzhou Kingmed Translational Medicine Research Institute Co., Ltd.	0.611
Guizhou	0.000	Xiamen	1.633	Guangzhou Technology Ltd.	0.407
Hainan	0.000	Suzhou	0.901	Guangdong Hybribio Biotech Co., Ltd.	0.185
Yunnan	0.000	Fuzhou	0.833	Zhejiang Pukang Biotechnology Co., Ltd.	0.167
Jiangxi	0.000	Wuhu	0.600	Qingyuan Biotechnology (Shenzhen) Co., Ltd.	0.111

Conclusions and policy implications

Conclusions

The present study describes the structural characteristics of China's COVID-19 patent cooperation network at the province, city, and applicant levels by using social network analysis based on data from the Incopat global patent database since 2020. The following conclusions are drawn:

The cooperation networks between developed provinces and cities are mainly formed through hierarchical and contagious diffusion. The three major urban agglomerations in China, i.e., the Beijing-Tianjin-Hebei Region, Yangtze River Delta, and Pearl River Delta, have a high integration of the COVID-19 industry. The cooperation between patent applicants is mainly based on kinship and business, supplemented by geographical proximity; specifically, kinship-based cooperation is the strongest, business-based cooperation has the widest scope, while proximity-based cooperation exists throughout these two main models of cooperation. The inter-regional cooperation level in China's COVID-19 patent cooperation network shows a decreasing trend from eastern to central to western regions. Eastern provinces and cities have stable partners; collaborative innovation in central provinces and cities need to be further improved; whereas there is still a lot of room for development in the western provinces and cities in establishing patent cooperation with other regions.

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TABLE 4 Closeness centrality of top 20 nodes in the COVID-19 patent cooperation network.

Province/ municipality	Closeness centrality	City	Closeness centrality	Applicant	Closeness centrality
Beijing	83.871	Beijing	13.399	Guangzhou Institute of Respiratory Health	1.777
Guangdong	70.270	Guangzhou	13.099	Wuhan Institute of Virology, Chinese Academy of Sciences	1.775
Shanghai	65.000	Shanghai	12.975	Fudan University	1.773
Jiangsu	63.415	Nanjing	12.693	Guangzhou National Laboratory	1.772
Zhejiang	61.905	Shenzhen	12.674	Southern Medical University	1.772
Hubei	60.465	Hangzhou	12.615	Wuhan Institute of Virology, Chinese Academy of Sciences	1.771
Tianjin	56.522	Wuhan	12.596	Sun Yat-Sen University	1.771
Henan	56.522	Shijiazhuang	12.557	The First Affiliated Hospital of Guangzhou Medical University (Guangzhou Respiratory Center)	1.769
Hebei	55.319	Suzhou	12.500	Huazhong Agricultural University	1.768
Chongqing	55.319	Xiamen	12.462	Guangzhou Kingmed Diagnostics Group Co., Ltd.	1.767
Liaoning	54.167	Chongqing	12.349	Guangzhou Kingmed Translational Medicine Research Institute Co., Ltd.	1.767
Sichuan	54.167	Tianjin	12.312	Shanghai Fosun Med-Tech Development Co., Ltd.	1.766
Anhui	53.061	Chengdu	12.312	The First Affiliated Hospital, Zhejiang University School of Medicine	1.765
Fujian	52.000	Zhengzhou	12.312	Southern University of Science and Technology	1.763
Shandong	52.000	Chaozhou	12.294	Qingdao Marine Biomedical Research Institute Co., Ltd.	1.763
Guizhou	50.980	Fuzhou	12.275	Guangzhou Kingmed Center for Clinical Laboratory Co., Ltd.	1.760
Hainan	50.000	Zhuhai	12.257	City University of Hong Kong Shenzhen Research Institute	1.760
Yunnan	50.000	Qingdao	12.221	Wuhan Keqian Biology Co., Ltd.	1.760
Jilin	49.057	Shenyang	12.184	Beijing Institute of Hepatology	1.758
Jiangxi	49.057	Haikou	12.148	Beijing Youan Hospital, Capital Medical AL University	1.758

Coastal provinces and cities, such as Beijing, Shanghai, and Guangzhou, occupy a core position in the network, and play an important role in utilizing structural holes and bridging. Patent applicants with high centrality are mostly firms. Research institutes and universities mainly play the role of bridges, and research institutes and firms make greater use of structural holes.

From the perspective of subgroup structure, the number of external relationships of subgroup nodes at the province and city levels is significantly greater than that of internal relationships. There is no large number of cliques or consequent information barriers, indicating a great potential for development. In contrast, there is a tendency for cliques to develop at the applicant level. The common characteristics of subgroups at this level are that the cooperation is based on kinship and business and that proximity-based cooperation exists throughout these two main models of cooperation.

Implications

The findings have the following implications.

First, efforts should be made to explore the potential for cooperation between patent applicants in the field of COVID-19.

TABLE 5 Structural holes of top 20 nodes in the COVID-19 patent cooperation network.

Province/ municipality	Effective size	Efficiency	Constraint	City	Effective size	Efficiency	Constraint	Applicant	Effective size	Efficiency	Constraint
Beijing	18.089	0.861	0.218	Beijing	35.619	0.937	0.121	Guangzhou Institute of Respiratory Health	5.583	0.931	0.384
Guangdong	12.031	0.752	0.366	Guangzhou	25.164	0.899	0.207	National Institute for Viral Disease Control and Prevention, China CDC	5.500	0.917	0.327
Shanghai	10.717	0.766	0.423	Shanghai	20.170	0.877	0.260	Guangzhou Technology Ltd.	4.265	0.853	0.385
Jiangsu	8.346	0.642	0.469	Shenzhen	12.224	0.815	0.348	Shandong Binzhou Academy of Animal Science and Veterinary Medicine Academy	4.000	1.000	0.344
Hubei	7.978	0.725	0.542	Nanjing	11.104	0.793	0.371	Qingyuan Biotechnology (Shenzhen) Co., Ltd.	4.000	1.000	0.264
Zhejiang	7.494	0.624	0.529	Hangzhou	10.916	0.780	0.426	Wuhan Institute of Virology, Chinese Academy of Sciences	3.588	0.897	0.418
Tianjin	6.245	0.781	0.469	Wuhan	9.141	0.762	0.434	Institute of Laboratory Animals Science, CAMS & PUMC	3.000	0.750	0.625
Chongqing	4.976	0.711	0.675	Tianjin	7.970	0.797	0.407	Peking University	3.000	0.750	0.563
Henan	4.517	0.645	0.662	Shijiazhuang	6.143	0.683	0.513	Wuhan Institute of Virology, Chinese Academy of Sciences	3.000	1.000	0.540
Hebei	4.168	0.595	0.630	Xiamen	5.678	0.710	0.474	Sun Yat-Sen University	3.000	1.000	0.429
Sichuan	4.053	0.675	0.625	Suzhou	5.462	0.607	0.570	Wuhan University	3.000	1.000	0.375
Anhui	3.262	0.652	0.767	Chongqing	5.450	0.779	0.672	Fudan University	3.000	1.000	0.360
Fujian	2.903	0.581	0.728	Hefei	4.400	0.880	0.474	Guangzhou Kingmed Diagnostics Group Co., Ltd.	3.000	1.000	0.360
Liaoning	2.511	0.419	0.940	Haikou	4.258	0.852	0.510	Guangzhou Kingmed Translational Medicine Research Institute Co., Ltd.	3.000	1.000	0.360

(Continued)

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TABLE 5 (Continued)

Province/ municipality	Effective size	Efficiency	Constraint	City	Effective size	Efficiency	Constraint	Applicant	Effective size	Efficiency	Constraint
Jilin	2.250	0.750	1.091	Chengdu	4.215	0.703	0.553	Guangzhou National Laboratory	3.000	1.000	0.333
Hainan	2.116	0.529	1.061	Chaozhou	3.790	0.632	0.601	Beijing University of Chemical Technology	2.600	0.867	0.540
Guizhou	2.035	0.509	1.009	Fuzhou	3.580	0.716	0.636	Guangdong Hybribio Biotech Co., Ltd.	2.370	0.790	0.574
Shandong	1.875	0.469	0.980	Dalian	3.303	0.661	0.885	The First Affiliated Hospital, Zhejiang University School of Medicine	2.200	0.733	0.980
Yunnan	1.580	0.395	1.084	Jiaxing	3.108	0.777	0.830	Guangzhou Vision Medical Laboratory Co., Ltd.	2.143	0.536	0.698
Shaanxi	1.107	0.554	0.934	Nantong	3.000	1.000	0.429	Qingyuan Biotechnology (Jiangsu) Co., Ltd.	2.000	1.000	0.625

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TABLE 6 E-I index analysis of the COVID-19 patent cooperation networks.

	Subgroup 1	Subgroup 2	Subgroup 3	Subgroup 4	Entire network
Province					
Number of internal relationships	20	32	0	6	58
Number of external relationships	37	43	2	30	112
E-I index	0.298	0.147	1.000	0.667	0.528
City					
Number of internal relationships	4	0	86	28	118
Number of external relationships	16	13	96	89	214
E-I index	0.600	1.000	0.055	0.521	0.544
Applicant					
Number of internal relationships	34	32	18	52	136
Number of external relationships	14	9	9	2	34
E-I index	−0.417	−0.561	−0.333	−0.926	−0.559

By developing technical information sharing platforms and incentive mechanisms, the low information transmission efficiency caused by technological distance can be overcome, and new cooperation can be established between patent applicants on an ongoing basis, thereby expanding the breadth of cooperation and exploring the potential for cooperation within the patent cooperation network.

Second, important nodes in the COVID-19 patent cooperation network should be encouraged to play a leading role. Accordingly, efforts should be made to promote the core nodes to carry out further patent cooperation, and to facilitate patent cooperation between the core and edge nodes under the leadership of the core nodes. In this way, the internal resource allocation of the network can be optimized, the sustainable development of the COVID-19 industry promoted, the bridging role of universities and research institutes further enhanced, and the resources of firms fully utilized.

Third and lastly, the government should subsidize the pharmaceutical R&D of relevant firms on a long-term basis and create technical reserves and strategic models for public health drugs to deal with large-scale public crises. Actions should be taken to establish a cross-regional cooperative group for COVID-19 patent development. Efforts should be made to fully exploit the technical advantages of industry-university-research organizations in coastal provinces and cities, promote the interconnection and interaction between the eastern and central regions, and strengthen the leading role of the east for the west, thereby achieving cross-regional COVID-19 cooperation and establishing a reasonable spatial pattern for promoting the COVID19 industry in China.

Despite its contribution, this study has some limitations. On the one hand, this study is limited to China, and did not investigate the COVID-19 patent cooperation between countries in the context of globalization. On the other hand, due to space limitations, the factors influencing China's COVID-19 patent cooperation network were not analyzed.

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/s.

Author contributions

WX contributed to conception and design of the study. JY and LQ organized the database and performed the statistical analysis. All authors contributed to manuscript revision, read, and approved the submitted version.

Funding

This work was supported by the Major Program of the National Social Science Foundation of China (Grant Number 21&ZD139).

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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frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 29 August 2022
DOI 10.3389/fpubh.2022.862487

Check for updates

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Health Economics, a section of the journal Frontiers in Public Health

RECEIVED 26 January 2022
ACCEPTED 08 August 2022
PUBLISHED 29 August 2022

CITATION
Chen Y, Zhao Z and Dai W (2022) Effect of medical innovation policies on the prevention and control of the COVID-19 and the impact of the "Belt and Road" economy.
Front. Public Health 10:862487.
doi: 10.3389/fpubh.2022.862487

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Effect of medical innovation policies on the prevention and control of the COVID-19 and the impact of the "Belt and Road" economy

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With the spread of the COVID-19, it is urgent for everyone to protect themselves. The introduction of the medical innovation policy has also brought certain effects to the prevention and control of the COVID-19. The specific effect will be reflected in the following research. This paper firstly analyzed research results related to medical innovation policy, COVID-19 prevention and control, and the "One Belt, One Road" economy, finding out the content that fits this research, and innovates the research work on this basis. Then, this paper provided a detailed explanation of medical innovation policies, the prevention and control of the COVID-19, and the "One Belt, One Road" economy. Among them, this paper focuses on the "One Belt and One Road," uses the α-convergence model to analyze the economic changes of the "One Belt and One Road," and conducts experimental tests in the medical field. The results have shown that from 2017 to 2019, the average hospitalization expenses paid by the pooled funds were 4986.19, 4997.34, and 4888.60 yuan, respectively.

KEYWORDS

medical innovation policy, new crown epidemic prevention and control, "One Belt, One Road" economy, convergence model, epidemic

Introduction

With the construction of the "Belt and Road," the initiative has gradually turned into practice, from theory to action. Some Western scholars and media have begun to play up a tone, believing that China's move is to manage its own sphere of influence and strive for regional dominance. Therefore, they regard China's "Belt and Road" initiative as the Marshall Plan during the Cold War, and even mistake it as China's political and security strategy under the shifting of global power. The purpose of this paper is to explore the relationship between the economic development of the countries along the "Belt and Road" cooperation mechanism that promotes each other rather than competes with each other. From the empirical results, it can be seen that the economic development of neighboring countries has a mutually promoting relationship in space. Moreover,

the rapid economic growth of a country can speed up the convergence of neighboring countries to their own steady state. That is to say, although the technological progress of a country makes the relative gap between neighboring countries tend to widen, due to technological spillover, the absolute growth rate of neighboring countries is improved, and the convergence to its own steady state is accelerated.

However, the Belt and Road Initiative aims at common development and common prosperity, and is characterized by inclusiveness and openness. First of all, today's world economy is increasingly interconnected, and the rapid growth and sustainable development of a country's economy must depend on the healthy economic development of other countries, which is completely different from the era background of the Marshall Plan. Secondly, most of the countries along the "Belt and Road" are developing countries, all of which have common problems of lack of funds and lagging technology, and they are all in the relatively lagging stage of urbanization and industrialization. Experience since World War II shows that developing countries that can develop labor-intensive industries can achieve rapid economic growth for about 30 years. The "One Road, One Belt" cooperation mechanism strengthens interconnection, trade flow, factor flow, and technology flow. It can enable relatively backward countries to share information and services of neighboring manufacturing and technologically advanced countries. It is also conducive to expanding the market size and achieving economies of scale. More importantly, due to the disappearance of China's demographic dividend, the comparative advantage of labor-intensive industries is gradually lost. By improving infrastructure construction, countries along the route can better absorb labor-intensive industries transferred from China. This huge process of labor absorption can not only promote employment in countries along the route, but also increase per capita income, expand consumption potential, and improve people's welfare.

The main innovations of this paper are:

1. This paper adopts the spatial panel data analysis method to overcome the problems of variable omission and endogeneity in the cross-sectional data analysis method. At the same time, after the introduction of spatial effects, the interaction of countries along the route is included in the model for analysis, and each country is no longer regarded as independent and unrelated economies. Therefore, it can better demonstrate that the "Belt and Road" initiative is about strengthening infrastructure construction, improving trade facilitation and enhancing factor flow, and trade exchanges can further strengthen the economic connections and spatial effects of countries along the route.
2. From the perspective of the integration of urban and rural residents' medical insurance, this paper quantitatively analyzes the changes in medical expenses before and after the integration of urban and rural residents' medical insurance. At present, most researches on medical expenses at home and abroad focus on one aspect of medical expenses. In addition, most domestic researches on medical insurance for urban and rural residents remain on system design, path selection and the necessity of integrating urban and rural medical insurance. It lacks the empirical analysis of related medical expenses after the integration of urban and rural medical insurance. Based on the background of the integration of urban and rural residents' medical insurance, this paper studies the current medical insurance cost control issues. It uses breakpoint regression to analyze the impact of urban and rural residents' medical insurance merger on medical expenses, which is innovative to a certain extent.
3. In the empirical analysis of this paper, due to the large amount of individual medical insurance data and information in a certain area, there is heterogeneity among individuals, and the information on individual characteristics is not very complete and accurate. In the model estimation, it may lead to ignore the role of some influence paths, and finally affect the model estimation result.
4. This study provides a detailed description of telemedicine in medical innovation policy, thus reflecting the benefits brought by medical innovation policy to society.

Related work

Many scholars have provided a lot of references for research on medical innovation policies, COVID-19 prevention and control, and the "Belt and Road" economy.

Moreira et al. analyzed whether several types of innovation affect relevant measures of medical institution performance, and empirically studies the relationship between innovation and performance. Based on a quantitative analysis of 34 Portuguese hospitals, the study gathered detailed information on each hospital's innovation portfolio. In addition, he classified hospitals by attribute type and geographic region, and performed statistical comparison tests to check for statistical differences. The study found that organizational innovation is related to process innovation and service innovation. In addition, service and process innovations impact operational performance. However, Moreira et al. cannot conclude that innovations in healthcare units have an overall impact on their financial performance (1).

Hossein proposed a fast online identification scheme to identify suitable linear state-space models for use in control algorithms. Then, he proved the convergence of recognition error sequences using Lyapunov candidate functions in both time and frequency domains (graph topology) (2).

Garmann-Johnsen et al. explored and conceptualizes how Nordic principles of employee engagement combined with corporate social media/web 2.0 can enable co-creation as an input in the digital transformation of healthcare delivery. Garmann-Johnsen et al. first introduced the Nordic model of employee engagement, which has proven successful in improving work-life efficiency and innovation. Garmann-Johnsen et al. then discussed how these engagement principles can be further enhanced by the latest web 2.0 technologies of enterprise social networking. To extend this further, Garmann-Johnsen et al. uses a practical template to exemplify the co-design of therapeutic pathway strategies (3).

Alam et al. aimed to explore the current state of digital transformation of the healthcare service sector in public, private and NGOs, as well as the management and technical challenges facing the digitisation of healthcare projects in Bangladesh. Research has shown that although there are still some problems with the digitization of the sector, difficulties and challenges can be overcome. According to the assessment of this sector, the scope of some areas needs to be further improved. These findings will help government agencies, policymakers, healthcare providers, and mobile phone companies make effective decisions about the digitization of healthcare services (4).

Proksch et al. compared the healthcare innovation outputs in 30 OECD countries using a multi-indicator approach and used cluster analysis to divide them into four distinct groups. The cluster consisting of the Scandinavian countries, the Netherlands and Switzerland showed the highest innovation output in terms of knowledge production and knowledge commercialization (5).

Shoemaker et al. supports the establishment of cross-jurisdictional approaches to facilitate streamlined data collection and uninterrupted connections and allow for meaningful analysis to inform national policy (6).

Lehoux et al. illuminated how entrepreneurs, investors and regulators can influence the value of emerging health technologies. The 5-year qualitative research program examines the process by which entrepreneurial clinical teams operating in Canada's publicly funded healthcare system envision, fund, develop and commercialize new health technologies. The results have suggested that policy-oriented initiatives, such as early health technology assessment (HTA) and evidence coverage, can provide technology developers with useful information about their early decision-making. But to foster technologies that bring more value to the healthcare system, policymakers must actively support the consideration of health policy issues in innovation policy (7).

The data of these studies are not comprehensive, and the results of the studies are still open to question, so they cannot be recognized by the public and thus cannot be popularized and applied.

Medical innovation policies, COVID-19 prevention and control and the "Belt and Road" economy

Medical innovation policy

The medical innovation policy is a reform of the existing medical policy, and some of the existing medical policies have some drawbacks. It not only consumes a lot of manpower and material resources, but also fails to achieve the expected results, so there is the emergence of medical innovation policies. Telemedicine is a very promising technology, and the description of this medical innovation policy will focus on telemedicine. In terms of content, telemedicine can be expressed as remote diagnosis, remote consultation, remote education, remote monitoring and remote treatment. From the service structure, the content of telemedicine services can be divided into three types, as shown in Figure 1. The first is the discussion, consultation or online medical education between medical institutions and medical institutions that does not involve the personal information of patients. The second is the direct remote diagnosis of patients by medical institutions, or the monitoring and management of chronic diseases through wearable devices and monitoring equipment. The third is to include medical activities between remote medical institutions and proximal medical institutions and patients, such as remote consultation, remote joint diagnosis and treatment, and remote surgery (8, 9). The so-called telemedicine should be understood as telemedicine in a broad sense, that is, telemedicine activities including tele-information transmission and tele-education (10).

The realization of today's telemedicine depends on the cooperation of many factors, but the importance of the network is self-evident. The birth of 5G has brought great changes to telemedicine, and the real-time information transmission of the network will enable many operations of telemedicine to be implemented (11, 12). The architecture diagram of "Internet + Smart Healthcare" is shown in Figure 2.

The research trends of Chinese and international telemedicine literature from 2008 to 2020 are shown in Figure 3 (13, 14). The research direction of Chinese telemedicine literature is shown in Figure 4 (15, 16).

Prevention and control of the COVID-19

The clinical manifestations of new coronavirus pneumonia include: sudden onset, chills and high fever, body temperature up to 39–40°C, and many systemic symptoms such as headache, general muscle and joint pain, extreme fatigue, and loss of appetite. It often has sore throat, dry cough, nasal congestion, runny nose, and retrosternal discomfort.

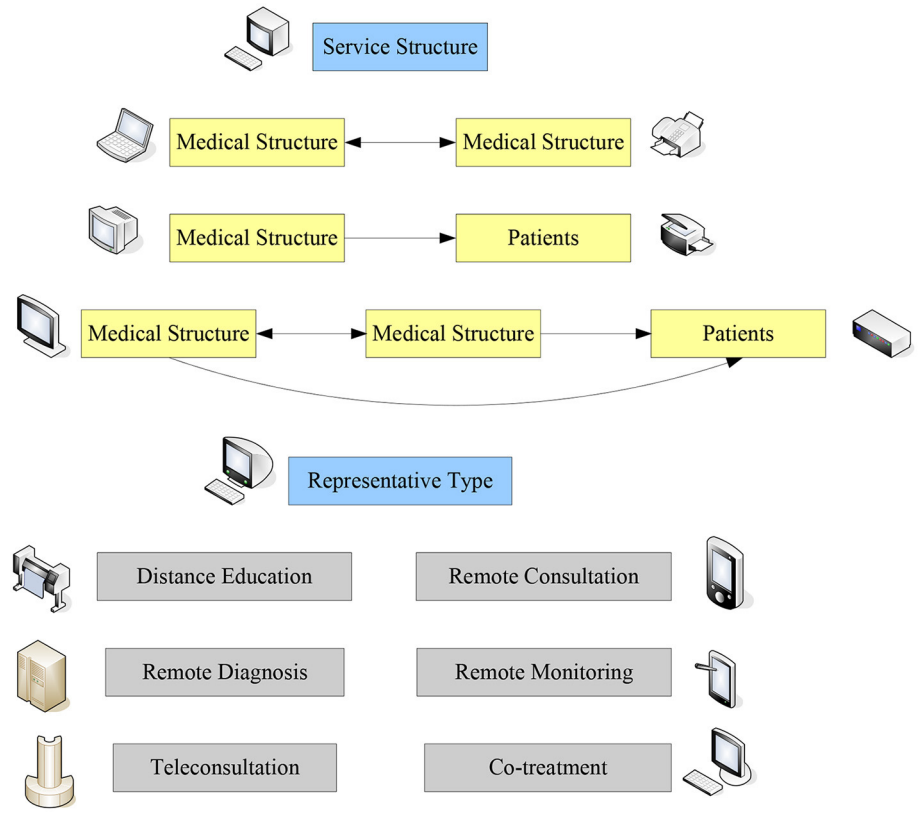


FIGURE 1
Content classification of telemedicine.

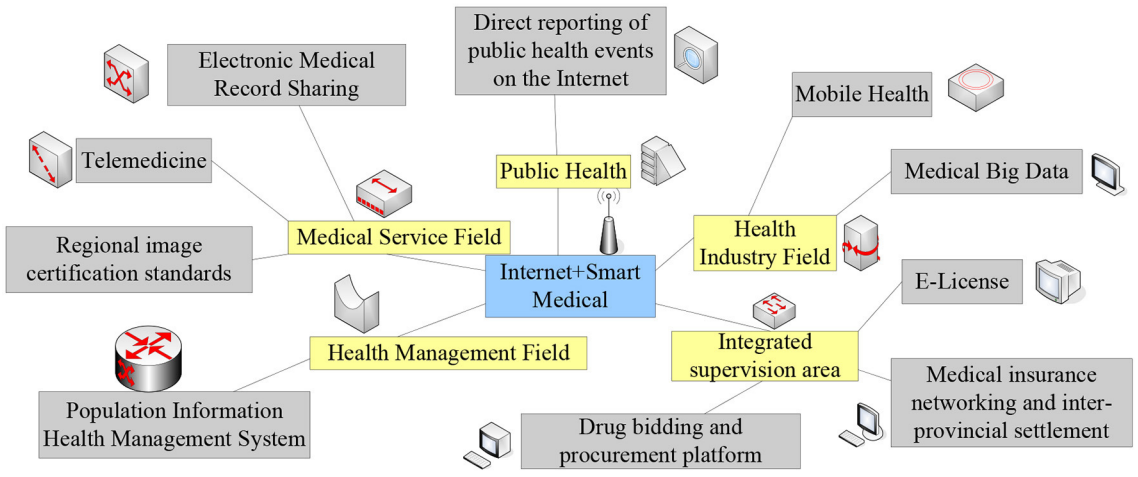


FIGURE 2
"Internet + Smart Medical" system structure.

The COVID-19 is now spreading all over the world, but it has been contained to a certain extent with the efforts of people. What people need to take seriously now is how to protect themselves. In order to do a good job in the prevention and control of the COVID-19, it is necessary to understand the transmission mode

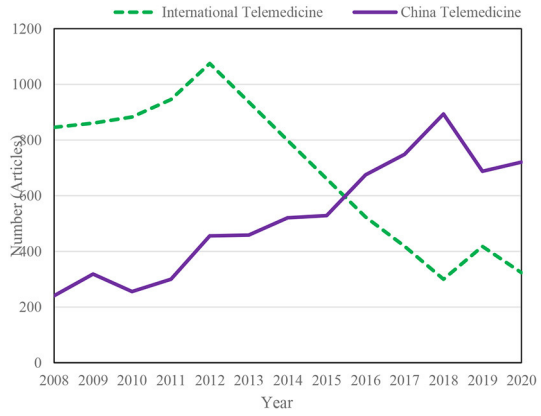


FIGURE 3
Research trends in Chinese and international telemedicine literature, 2008–2020.

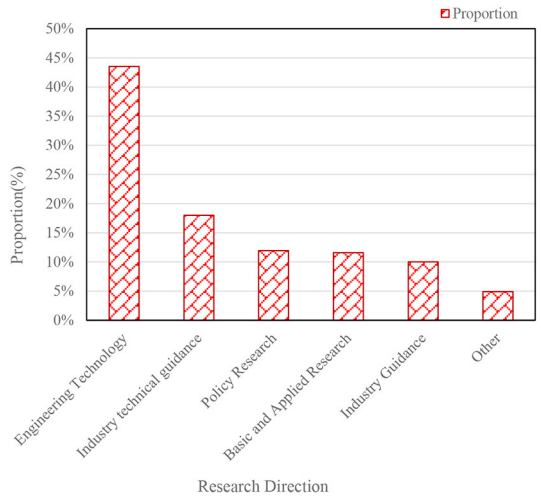


FIGURE 4
Research directions in Chinese telemedicine literature.

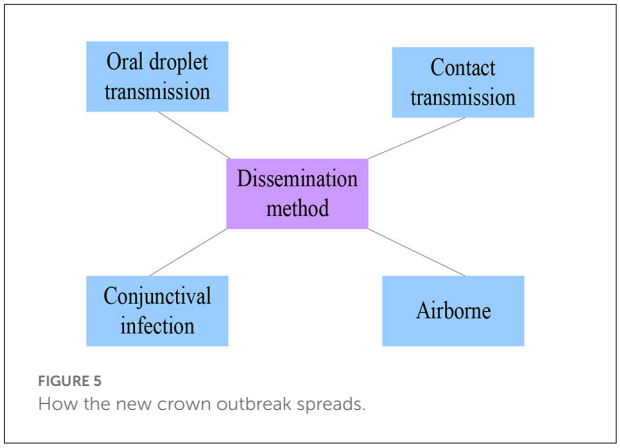


FIGURE 5
How the new crown outbreak spreads.

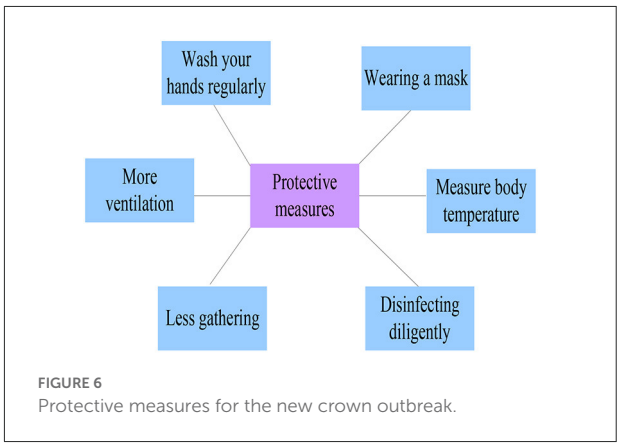


FIGURE 6
Protective measures for the new crown outbreak.

of the COVID-19 from the source, as shown in Figure 5 (17, 18).

After understanding the transmission mode of the COVID-19, a series of protective measures starting from blocking the transmission can be formulated. The specific protective measures are shown in Figure 6 (19, 20).

"Belt and Road" economy

The "Belt and Road" construction is not only for China to deal with its own development problems, but more importantly, it injects new impetus into the world economic growth after the financial crisis (21, 22). Under the pressure of the overall weakness of the world economy and the structural contradictions of its own development, China's economy will enter a state of medium-high growth. In order to maintain the steady growth of China's economy, it has overcome difficulties from home and abroad (23, 24). The route of the "Belt and Road" is shown in Figure 7.

Before the "One Belt, One Road" initiative was proposed, many people believed that the Silk Road was a small intestine path that could only pass camels and horses, and could only transport light materials such as spices, porcelain and silk. In fact, the Silk Road was formed by the diffusion and radiation of several land and sea passages through different regions. According to different modes of transportation, it can be divided into land and sea Silk Road. Among them, the land Silk Road can be divided into north and south lines according to the geographical trend. The southern line mainly refers to the vast area from Sichuan to India and even Southeast Asia, and the northern line mainly refers to the area starting from Chang'an, passing through the Hexi Corridor, the Western Regions, and reaching the Mediterranean Sea in the west to ancient Rome.

This paper analyzes the economic growth convergence and spatial effects of countries along the "Belt and Road" by using spatial measurement methods, using panel data, and introducing

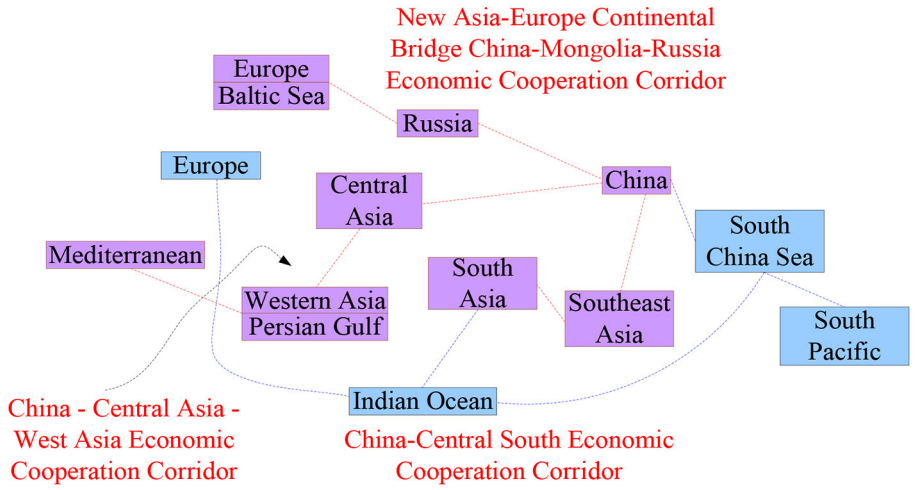


FIGURE 7
The route of "One Belt, One Road".

spatial effects. First, this paper estimates and analyzes the absolute α convergence of the economies of countries along the "Belt and Road." Hausman's test was used in the selection of fixed-effects and random-effects models. At the same time, after introducing relevant control variables such as population growth rate, capital, labor force, and the proportion of service industry in GDP, etc., this paper estimated and analyzed the convergence of economic conditions α in countries along the "Belt and Road."

Since the "Belt and Road" initiative is a regional cooperation plan emerging in recent years, there are few empirical analyses on the economic growth convergence and spatial effects of countries along the route. Therefore, this paper analyzes the economic growth convergence and spatial effects of countries along the "Belt and Road" by using spatial measurement methods, using panel data, and introducing spatial effects. Countries are no longer seen as separate, unrelated economies. Rather, it is believed that they have technological spillovers, that the flow of factors of production and trade are correlated, and the closer the distance or the closer they are to each other, the stronger the correlation. First, analyzing whether there is absolute α-convergence and conditional α-convergence in the economies of countries along the "Belt and Road." Secondly, analyzing the effects of factors of production, population growth, and industrial structure on economic growth. Thirdly, comparing the estimation results of the model without considering the spatial correlation and the model considering the spatial correlation, it shows whether there is a spatial effect in the economic growth of the economies along the "Belt and Road." Finally, it is explained that the "Belt and Road" initiative is a regional cooperation mechanism that aims to seek common growth and is characterized by openness and inclusiveness. It can bring huge potential markets and supplements of funds and technologies to each member state, and it also requires the joint efforts of countries and regions along the route to improve the initiative.

The "Belt and Road" initiative adheres to the cultural tradition of the ancient Silk Road, and emphasizes openness, tolerance and harmony in cultural concepts. In the field of economic cooperation, we adhere to the concept of common development, benefiting ourselves and others, and "doing what you do not want to do to others," in order to promote the integration and cooperation of different civilizations, and avoid the dilemma caused by civilizational and economic conflicts. At the same time, it can prevent "cross-infection" between multiple negative factors.

Cooperation focus of the Belt and Road Initiative:

People-to-people bonds are the social foundation of Changyi under the Belt and Road Initiative. Adhering to and carrying forward the concept of peaceful and friendly cooperation on the ancient Silk Road, respecting the wisdom and advantages of different civilizations, it extensively carries out cultural exchanges, academic exchanges, talent training cooperation, and volunteer services. Cooperation in running schools is carried out to strengthen mutual talent training and establish a humane scholarship system, which is conducive to deepening exchanges and mutual trust between countries and civilizations. Strengthening tourism cooperation and simplifying passport application procedures can not only enjoy the social returns brought by tourism resources, but also strengthen non-governmental exchanges and cooperation. It should strengthen cooperation with neighboring regions and countries in the fields of information exchange of infectious disease epidemics, communication of prevention and control technologies, and assistance to improve the ability to respond to public health

TABLE 1 The results of maximum likelihood estimation of absolute beta convergence of panel data for 20 countries along the route.

Variables (coefficients)	Not considering the spatial phase	Spatial lag	SARAR	Spatial error autocorrelation
Inyt	−1.043	−1.01427	−1.0476	−1.0245
Splag		1.248	1.273	
Spar			1.452	1.24

TABLE 2 Status of medical institutions in a city.

Ownership	Total number of institutions	Total number of beds	Registered capital (million yuan)	Floor space (square meters)	Building area (square meters)
Non-profit (government-run)	887	14,043	200921.18	1164684.30	1517653.00
For-profit (not government-run)	973	2,944	273109.12	1273283.32	1189953.02
Non-profit (not government-run)	929	2,565	29395.40	456637.43	239253.77
Total	2,789	19,552	503425.73	2894606.05	2946859.79

crises and other natural disasters. At the same time, political parties and non-governmental organizations should be used as bridges to strengthen cooperation and exchanges in politics, humanities, health, and charity.

The proposal and implementation of the "One Belt, One Road" strategy marks China's transformation from the traditional role of bystander and participant to a new role in shaping international cooperation and governance. However, the "One Belt, One Road" strategy is not only a regional development strategy, but also an international cooperation strategy to drive the global economy out of the trough. The number of countries involved, the size of the area, and the amount of capital involved are rare in Chinese history and even in global history. The economic development, ideology and social structure of the countries along the "Belt and Road" construction are complex. How China strengthens cooperation with countries along the route while playing its leading role has become an important factor affecting the implementation of the "One Belt, One Road" strategy and achieving the desired results. Therefore, to ensure that the "Belt and Road" initiative can be effectively carried out, this paper proposes the following policy recommendations:

(1) Strengthen cooperation in border areas. According to the center-periphery theory of new economic geography, there are opportunities to invest and build factories in areas far from central cities, which can form new active economic belts. Moreover, the new era has become an important platform for exchanges and trade between countries because the border area is in a state of peaceful development as a whole. In addition, the extensive economic, cultural and social exchanges in the border areas have a good trade foundation and can promote the activation of the cross-border sub-regional market. The "Belt and Road" construction spans a large number of countries along the way, and the border areas are often areas where technology, capital, and human capital are relatively backward. According to the classical growth model, funds have higher returns in these areas. The formation of industrial clusters by investing in factories can well-promote cooperation and trade between countries, and at the same time change the backwardness of this region and improve local welfare. This is in line with the openness, inclusiveness and common prosperity of the Belt and Road construction.

(2) China should strengthen cooperation with major countries along the route. The "Belt and Road" construction is a cooperation mechanism that supports the economic rise of China and Asia and injects fresh blood into the global economic recovery. Although proposed and dominated by China, relying solely on China's power is not enough. Therefore, strengthening cooperation with countries and regions along the route, especially the major countries along the route, is related to the smooth implementation of the "Belt and Road" construction. First, in the construction of the "Belt and Road," China and the United States have economic and political competition in Southeast Asia, South Asia, the Middle East and other regions. Especially in the Middle East and the Gulf region, it has always been a key strategic area for US energy supply and control of the world energy order. China's energy cooperation, expansion of trade, and infrastructure investment in the region will make the United States feel huge challenges and unease, and will easily lead to US countermeasures and interference. In fact, China and the United States have huge potential and prospects for cooperation in energy and resource development and trade along the "Belt and Road." The Middle East, as the world's "powder keg," has been in turmoil in the region. Whether it is terrorism or territorial disputes between regions, China and the United States need

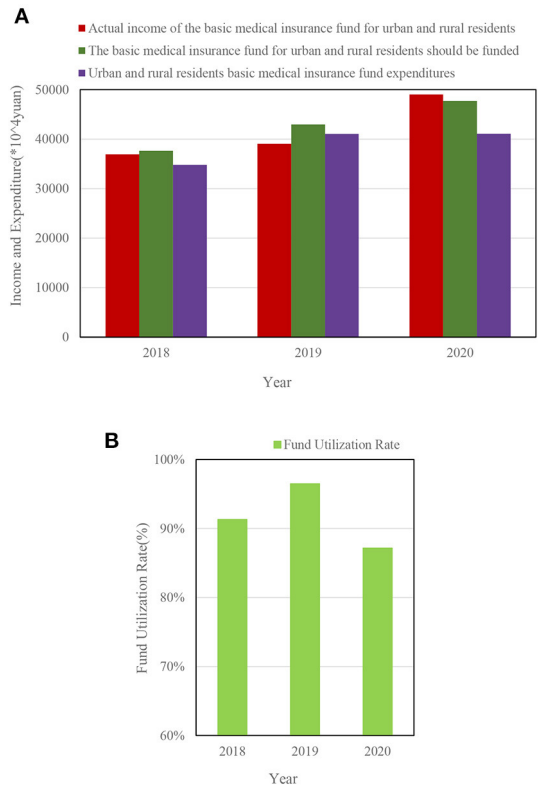


FIGURE 8
(A) Income and expenditure of basic medical insurance fund for urban and rural residents in 2018–2020. **(B)** Utilization rate of medical insurance funds for urban and rural residents in 2018–2020.

to work together to maintain regional stability and ensure the normal operation of energy supply and trade order. This is in the interests of both countries and the world. Therefore, China and the US should cooperate in more fields to expand common interests, enhance consensus, and eliminate US resistance to China's "One Road and One Belt" construction.

Second, China should strengthen cooperation with India. As the two most populous developing countries in the world, China and India have developed rapidly in their economy and energy demand, accounting for the vast majority of the world's energy increment. Therefore, the cooperation between China and India in energy is very important. In terms of energy demand, due to the high dependence of the two countries on oil imports, there is fierce competition between the two countries in seeking energy exporters and finding crude oil origins. Coupled with the non-renewable nature of oil, the characteristics of zero-sum game gradually emerged. As a result, it is very easy to cause tensions in the economic fields of the two countries, and at the same time raise market prices, causing heavy losses to both sides. Therefore, under the framework of the "Belt and Road" construction, the two sides should cooperate with each other in mutual trust, ensure a sound energy market order, play the role of major powers in Asian energy cooperation, and at the same time, strengthen the right to speak together in global energy governance. More importantly, India is a big developing country, and strengthening the infrastructure construction in the "Belt and Road" construction is of great significance to the backwardness of infrastructure. It is also an important foundation on which India can develop rapidly. India should not adopt a passive and passive attitude, but should exert its influence and due responsibilities in the region to speed up the implementation of this strategy and ensure the smooth progress.

(3) Actively play the role of the AIIB. The focus of the "Belt and Road" construction is infrastructure construction and investment and trade, and the Asian Infrastructure Construction and Investment Bank (hereinafter referred to as "AIIB") is a multilateral investment and financing bank initiated by China. At present, it has 57 member countries, covering Europe, Asia, Africa, Oceania and Latin America (except the United States and Japan). The AIIB closely links the interests of its founding member countries. Among them, most countries in Southeast Asia and South Asia directly benefit from the improvement and connectivity of infrastructure in the construction of the "Belt and Road," while other member countries will win trade benefits due to the economic integration of Europe, Asia and Africa promoted by the construction of the "Belt and Road." As the largest investor in the AIIB, China should try its best to play the role of the AIIB in reducing investment and financing costs and investment risks. At the same time, the renminbi has joined the SDR, which should promote the renminbi's function as a bilateral and multilateral settlement and reserve currency, and improve the operational efficiency of the Asian capital currency market. In addition, for the AIIB to play its role effectively, it must address the following issues. First of all, it is necessary to do a good job in investment and financing risk assessment, so that capital can play the highest efficiency. Second, because many countries along the "Belt and Road" are relatively backward countries, their credit ratings are relatively low. When issuing loans, it should strengthen supervision and knowledge to avoid losing all investment. Finally, the financial markets and financial systems of countries along the route are still very immature. On the one hand, it is necessary to strengthen the construction of its own financial system. On the other hand, China should learn from the World Bank and the Asian Development Bank in terms of risk assessment and project evaluation, actively learn from developed countries in Europe and the United States, strengthen exchanges, and

strive to integrate with the developed Western financial system as soon as possible.

α convergence model

The specific form of the neoclassical growth model is as follows:

$$W = F(P, Q\mu) \tag{1}$$

W is the output, Q represents the technical level, P and μ represent the capital stock and labor quantity, respectively, and $Q\mu$ represents the effective labor quantity. The effective output per capita is:

$$f(p) = F(P, Q_\mu)/Q_\mu = F(P/Q_\mu) \tag{2}$$

If U represents the total national investment, and saving equals investment when national income reaches equilibrium, then the per capita capital change Δp can be expressed as:

$$\begin{aligned} \Delta p &= (U/Q\mu) - (a+b+c)p = (jW/Q\mu) - (a+b+c) \\ p &= jf(p) - (a+b+c)p \end{aligned} \tag{3}$$

Among them, a represents the population growth rate, b represents the technological growth rate, and c represents the depreciation rate.

If t_p is used to represent the growth rate of capital per capita, there are:

$$t_p = d(\Delta p)/dp = j(df(p)/dp) - (a+b+c) \tag{4}$$

The convergence of per capita income is generally measured by α convergence, which means that countries or regions with lower per capita income have higher economic growth rates than countries or regions with higher per capita income. According to different convergence conditions, it can be divided into absolute α convergence and conditional α convergence.

Absolute α convergence refers to the differences in production conditions (factor endowments, production technology, location factors, knowledge reserves, etc.) and production systems in different economies in the initial stage. Economies in different countries or regions will eventually converge to the same steady state level. The specific manifestation is that the backward economies have a higher growth rate than the advanced economies, which leads to the continuous narrowing of the gap between the income levels of the backward economies and the advanced economies. In the end, the same steady state level will be reached, and the balanced and stable development of the economy in different regions will be realized.

The basis of the alpha convergence model is the Cobb-Douglas production function, which is set as:

$$W_\mu = (Q_\mu K_\mu)^{1-\beta} P_\mu^\beta, 0 < \beta < 1 \tag{5}$$

Among them is the total output of production, W_μ is the measurement coefficient of production technology, Q_μ is the input of labor factors, and K_μ is the total input of production capital.

This results in output per capita:

$$w_\mu = W_\mu/Q_\mu K_\mu = f(p_\mu) = p_\mu^\beta \tag{6}$$

Saving equals investment when the national income is in equilibrium, that is:

$$jW_\mu = U_\mu \tag{7}$$

So the total capital change is:

$$\Delta P = jW_\mu - (a+b+c)P_\mu \tag{8}$$

The change in capital per capita is:

$$\Delta p_\mu = jw_\mu - (a+b+c)p_\mu = jp_\mu^\beta - (a+b+c)p_\mu \tag{9}$$

$\Delta p_\mu = 0$, the economy reaches a steady state, and the capital per capita at this time is:

$$p^{'} = (j/a+b+c)^{1/1-\beta} \tag{10}$$

Therefore, the output per capita at equilibrium is:

$$w_\mu^{'} = W_\mu/K_\mu = Q_\mu w_\mu = Q_\mu f(p_\mu^{'}) = Q_\mu p_\mu^{'} \tag{11}$$

Taking the logarithm of both sides gives:

$$\ln w_\mu^{'} = \ln Q_\mu + \ln p_\mu^{'} \tag{12}$$

Generally expressed as:

$$\ln w_\mu^{'} = \ln w_0 + b \tag{13}$$

Thus, it is further deduced that the economic convergence rate is α:

$$\ln w_\mu = (1-\alpha)\ln w_{\mu-1} + \alpha \ln w_\mu^{'} + \alpha b\mu \tag{14}$$

$$\alpha = (1-\beta)/(a+b+c) \tag{15}$$

Since the model assumes that a, b, and c are fixed, that is to say, the three variables of convergent economies are consistent, and the general situation is further deduced:

$$\ln w_{n,\mu} = (1-\alpha)\ln w_{n,\mu-1} + \alpha \ln(w_{n,0}^{'} + b\mu) + \phi_{n,\mu}^0 \tag{16}$$

where n represents a region or country, and $\phi_{n,\mu}^0$ is a random item.

Let $\beta_0 = \alpha \ln w_{n,0}^{'}, \gamma = (1-\alpha)$, so we get:

$$\ln w_{n,\mu} = \gamma \ln w_{n,\mu-1} + \beta_0 + \phi_{n,\mu}^0 \tag{17}$$

TABLE 3 Reimbursement treatment.

	New agricultural cooperative	Urban health insurance	Urban and rural medical insurance
Starting Pay Line	0	0	0
Reimbursement rate (%)	40	60	60
Annual cap line (million yuan)	0.3	5	10.5

Thus, the absolute alpha convergence model is obtained:

$$\ln(w_{n,\mu}/w_{n,\mu-1}) = \beta_0 - \alpha \ln w_{n,\mu-1} + \phi^0_{n,\mu} \quad (18)$$

To get the general expression, let $\alpha_0 = -\alpha$, get:

$$\ln(w_{n,\mu}/w_{n,\mu-1}) = \beta_0 + \alpha_0 \ln w_{n,\mu-1} + \phi^0_{n,\mu} \quad (19)$$

If α <0, there is absolute α convergence, otherwise, it does not exist. This model is based on the following assumptions: ① The initial state income level is independent of surrounding areas and is exogenous. ② Assume the same population growth rate and technological growth rate in each region. ③ The convergence speed of each region is equal.

Conditional α convergence means that although different countries or regions have similarities in terms of economic structure and market potential, it can be expressed as:

$$\ln(w_{n,\mu}/w_{n,\mu-1}) = \beta_0 + \alpha_0 \ln w_{n,\mu-1} + \lambda Z_{n,\mu} + \phi^0_{n,\mu} \quad (20)$$

$Z_{n,\mu}$ is the control variable. If α <0, there is a condition of α convergence, otherwise, it does not exist. The difference between absolute α convergence and conditional α convergence is that the former means that different economies eventually converge to the same steady state level, and there is no gap between different economies. The latter means that different economies are affected by different factors and eventually converge to their own steady state, and the gap between them still exists.

In the absolute α-convergence model of the economy of the 20 countries along the route, both spatial lag autocorrelation and spatial error autocorrelation should be considered in the selection of the panel model. By using the Hausman test, it is found that a fixed effect model should be used, but the spatial correlation in the model may be spatial lag autocorrelation, spatial error autocorrelation, or both. In this paper, the maximum likelihood method is used to estimate the spatial econometric model, and the results are shown in Table 1.

The status of medical institutions in a city is shown in Table 2.

Figure 8 shows the income and expenditure of the basic medical insurance fund for urban and rural residents in a certain district.

Figure 8A shows that the income and expenditure of the basic medical insurance fund for urban and rural residents in a certain district increased year by year from 2018 to 2020.

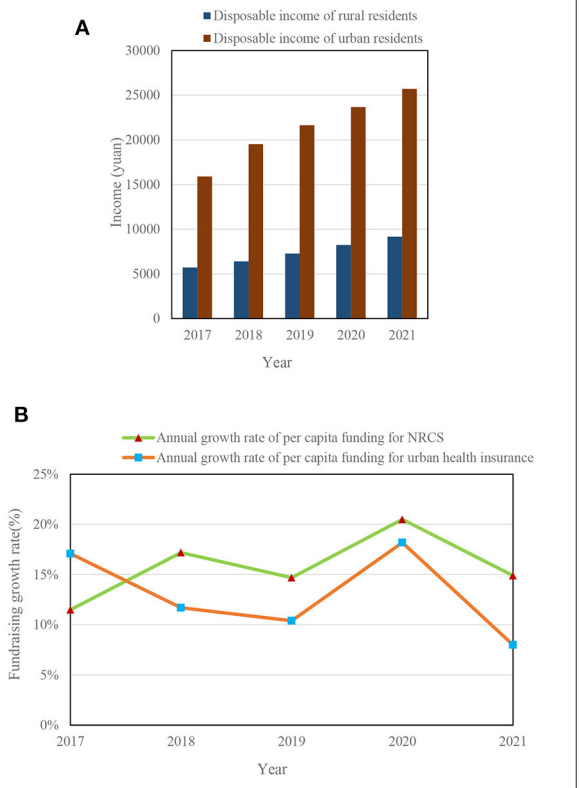


FIGURE 9
(A) Disposable income of rural residents in 2017–2021. **(B)** Average annual growth rate of per capita fundraising in 2017–2021.

Figure 8B shows that the utilization rates of medical insurance funds in 2018–2020 were 91.31, 96.49, and 87.16%.

Table 3 shows the reimbursement benefits of urban and rural residents' medical insurance, urban residents' medical insurance, and new rural cooperative medical care for special slow outpatient services in a city.

Table 3 shows that the new medical insurance system attaches great importance to improving the benefits of special chronic diseases in the process of integrating medical insurance for urban and rural residents.

Figure 9 shows the per capita disposable income and per capita financing standards of a district from 2017 to 2021.

TABLE 4 2018–2021 disparity between disposable income of urban and rural residents in a district and disparity in funding standards for participation in insurance.

Year	Urban-rural income gap (yuan)	Income gap growth rate (%)	Urban and rural health insurance funding gap (yuan)	Funding gap reduction rate (%)
2018	15,149	31.25	49	21.45
2019	16,482	10.45	39	19.14
2020	17,452	8.15	42	10.54
2021	18,946	6.49	0	100

Figure 9A shows that from 2017 to 2021, the disposable income of rural residents increased from 5,728 to 9,166 yuan, and the disposable income of urban residents increased from 15,914 to 25,720 yuan. Figure 9B shows that the average annual growth rate of per capita fundraising for NCMS is 15.76%, and that for urban medical insurance is 13.08%.

From 2018 to 2021, the gap between the disposable income of urban and rural residents in a certain district and the gap between the insurance financing standards is shown in Table 4.

Table 4 shows that the urban-rural income gap widened from 2018 to 2021, and the urban-rural income gap increased from 15,149 to 18,946 yuan from 2018 to 2021.

Figure 10 shows the reimbursement of medical expenses for insured urban and rural residents in a district from 2017 to 2019.

Figure 10A shows that the average hospitalization expenses paid by the pooled funds from 2017 to 2019 were 4,986.19, 4,997.34, and 4,888.60 yuan, respectively. Figure 10B shows that from 2018 to 2019, the average out-of-pocket expenses for special outpatient clinics jumped from RMB 5.68 to 82.94.

The basic social medical insurance financing standards for urban and rural residents in a city over the years are shown in Table 5.

Table 5 shows that from 2017 to 2018, the financing standards of urban and rural residents' medical insurance have been increasing rapidly, which greatly increased the income of urban and rural residents' medical insurance pooling fund, which is conducive to increasing the payment capacity of the pooling fund.

Figures 11A,B show the reimbursement of special outpatient expenses for adults and minors under medical insurance for urban and rural residents in a certain district, respectively.

Figure 11A shows that from 2017 to 2019, the reimbursement of the pooled fund for the special outpatient expenses of resident medical insurance adults in a district was 468.5, 501.4, and 483.8 yuan. Figure 11B shows that from 2017 to 2019, the personal reimbursement of resident medical insurance minors in a certain district for special outpatient expenses was 0.8, 0.4, and 6.7 yuan. In addition, in 2019, the average expenses of minors in special outpatient clinics showed strong growth.

Discussion

The "Belt and Road" is a development path featuring win-win cooperation, mutual respect and mutual trust. It not only meets the needs of China's economic transformation and coping with internal and external pressures, but also meets the needs of countries along the route to accelerate economic growth and strengthen infrastructure. The joint construction of the "Belt and Road" is based on goal coordination and policy communication, with the aim of pursuing common economic growth and prosperity of all countries, oriented to enhance the overall competitiveness of the region, and aimed at narrowing the economic gap between each other. Under the existing framework of bilateral and multilateral, regional and sub-regional cooperation, it would further strengthen the connectivity of countries along the route and improve the level of trade facilitation, so as to inject new impetus and energy into regional economic development.

The prevention and control of the new crown epidemic should strengthen epidemic prevention and control safety education, and pay attention to the epidemic situation in real time. Carry out health education and publicity work for all personnel (managers present and left-behind duty personnel), and popularize epidemic prevention and control knowledge and prevention and control requirements. Wear masks, wash hands frequently, measure body temperature, disinfect frequently, ventilate more, and gather less together on a daily basis, and guide all staff to work together to prevent and control the epidemic. Do not believe rumors, do not spread rumors, and resolutely win the battle against the epidemic.

Conclusion

Under the circumstance that the "One Belt, One Road" strategy has not been implemented (the natural state), whether in the absolute α-convergence model or in the conditional α-convergence model, the parameter estimation results have shown that there is a significant positive space for the 20 countries along the "Belt and Road" construction, which verified the first hypothesis of this paper. That is, in the natural state, the economic development of various countries has a relationship of

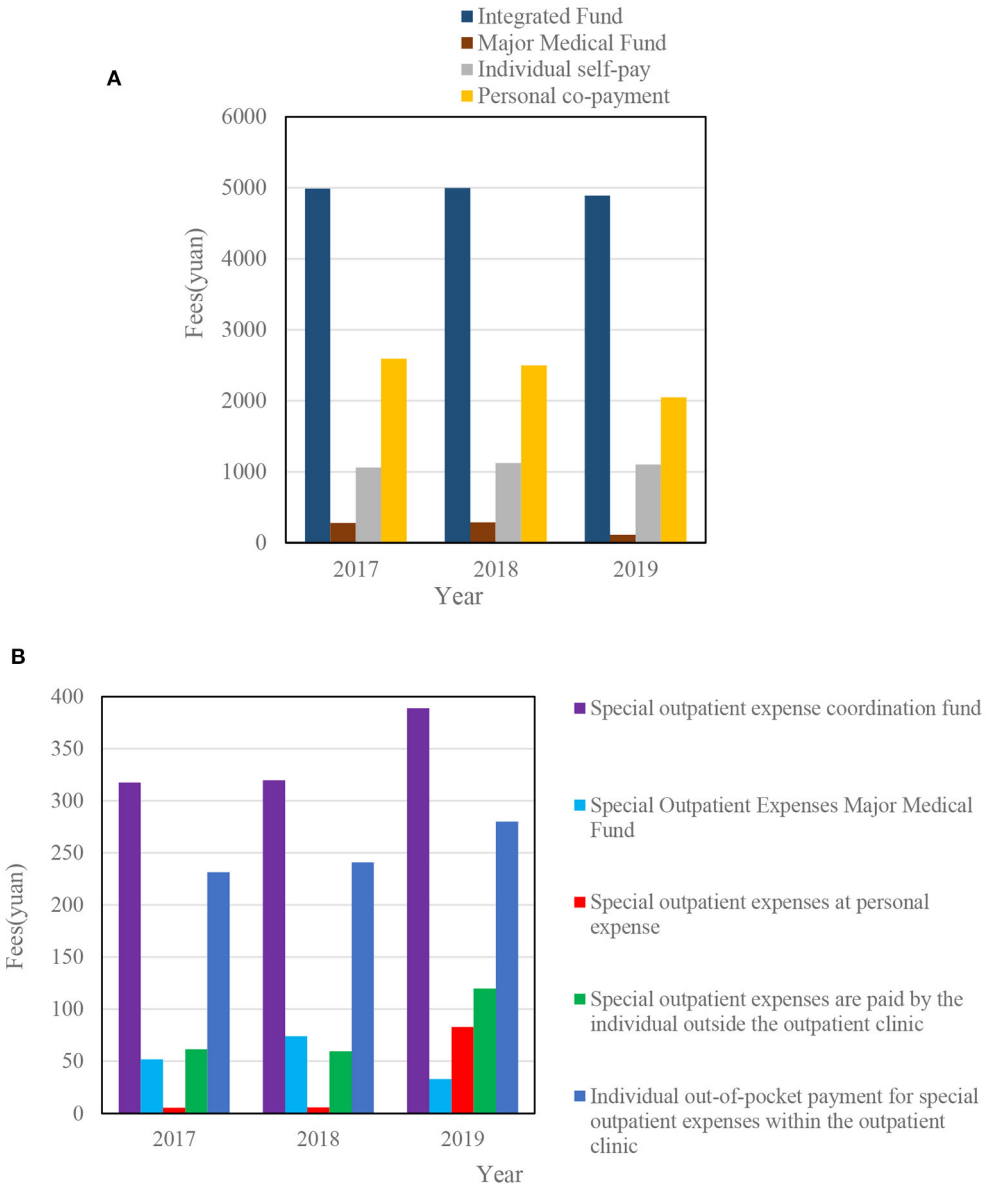


FIGURE 10
(A) Reimbursement of medical expenses for urban and rural residents in 2017–2019. **(B)** Changes in the average out-of-pocket expenses of specialized outpatient clinics for urban and rural residents from 2017 to 2019.

mutual promotion rather than mutual competition. Then, after the implementation of the "One Belt, One Road" strategy, by strengthening the construction of interconnected infrastructure and trade facilitation, the connection between countries along the route will be strengthened. And it can promote the dissemination of knowledge and technology. The dissemination of knowledge and technology helps to improve the important factor affecting the production function in the classical growth model, that is, technical means. In this way, if countries along the route can jointly promote infrastructure construction, strengthen mutual connectivity, and give play to their respective comparative advantages. Countries such as Vietnam and India can take advantage of huge demographic dividends, undertake manufacturing transfers from China and other countries, and increase investment in R&D and technology. Then it is expected to catch up with the more developed countries along the route with a higher growth rate. In the conditional α-convergence model, from the perspective of production factor input, capital and population growth are significantly positive for economic growth. It shows that there are still huge demographic dividends

TABLE 5 Funding standards of basic social medical insurance for urban and rural residents in a city in previous years.

Year	New agricultural cooperation (yuan)		Urban residents' medical insurance (yuan)	
	Individual contribution	Individual contribution	Individual contribution	Individual contribution
2017	70	320	120/50	320
2018	90	380	120	380
2019	120	420	120	420
2020	150	450	150	450
2021	180	450	180	450

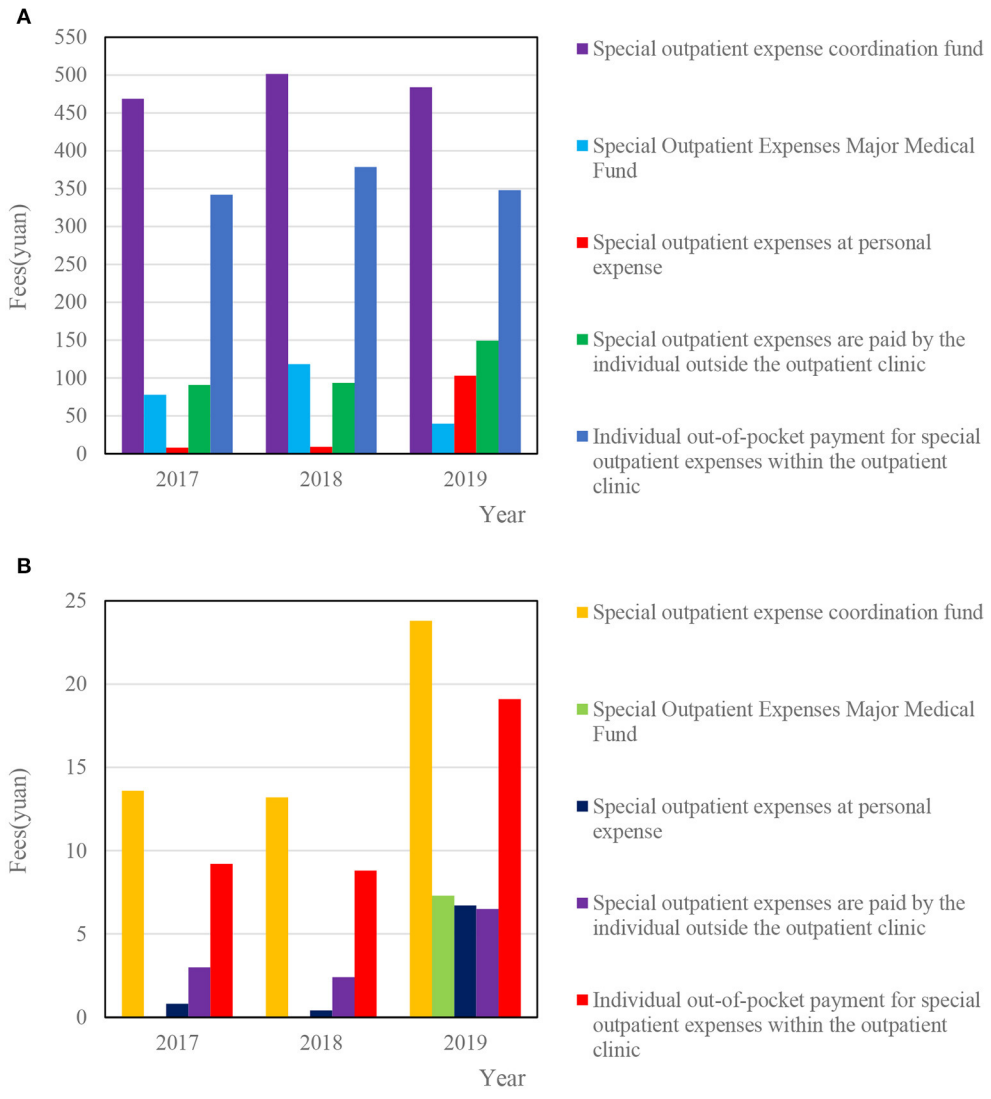


FIGURE 11
(A) Special outpatient coordination fund reimbursement in 2017–2019. **(B)** Individual reimbursement of medical insurance minors for special outpatient expenses in 2017–2019.

in the countries along the "Belt and Road," and the efficiency of capital investment on economic growth is much higher than that of labor input. From the perspective of industrial structure, the proportion of industrial added value in the added value

of workers and peasants has a significant positive effect on the economic growth of countries along the route, indicating that industry plays an important role in promoting economic growth. This research is only aimed at the prevention and control of the COVID-19 and the "One Belt, One Road" economy. In fact, it can also be considered in a wider range, such as the impact of medical innovation policies on employment and so on.

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.

Ethics statement

Ethical approval for this study and written informed consent from the participants of the study were not required in accordance with local legislation and national guidelines.

Author contributions

YC: work concept or design and draft article. ZZ: data collection. WD: make important revisions to the article and approve final article for publication. All authors contributed to the article and approved the submitted version.

Funding

This work was supported by Major project of Beijing Social Science Foundation Research on Financial Support System Adapting to the Coordinated Development of Strategic Emerging Industries in Beijing-Tianjin-Hebei, No. 20ZDA11.

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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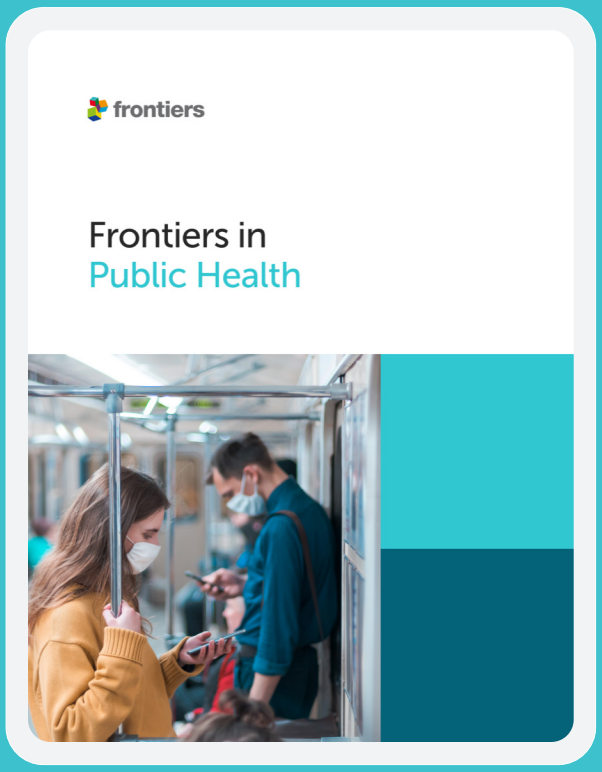
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