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Digitalization and nutrition: How does internet use affect dietary diversity among rural residents?

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The nutritional status of rural residents is transitioning from "eating enough" to "eating well," but dietary imbalance and low dietary quality continue to be significant concerns. This study empirically analyzes the impact of internet use on dietary diversity among rural residents based on the China Health and Nutrition Survey (CHNS). Firstly, the study found a significant positive correlation between internet use and dietary diversity among rural residents. Secondly, the impact of internet use on rural dietary diversity varies by location and individual, with a significant positive impact on the dietary diversity of Han Chinese, highly skilled individuals, and rural residents in non-township areas, but no significant impact on ethnic minorities, low-skilled individuals, and rural township areas, while the impact is more significant in low-density communities than in high-density communities. Furthermore, internet use has a significant positive impact on the dietary diversity of animal-based foods among rural residents, but no significant impact on plant-based foods. Finally, mechanistic analysis shows that internet use primarily improves the dietary diversity of rural residents through direct pathways of increased nutritional literacy and indirect pathways through increased household income. This paper provides a possible new perspective for improving the nutritional structure of rural residents from a "technology-society" perspective and offers policy implications for improving the "uneven" impact of internet use on the nutritional structure of different groups.

KEYWORDS

dietary diversity, digitalization, food safety, internet, rural residents

1 Introduction

Ensuring food safety and addressing inadequate nutrition are critical issues and objectives for the United Nations' sustainable development. These are also significant concerns for the government and various societal sectors in China. The National Nutrition Plan (2017–2030) states that "nutrition is an important part of maintaining life, growth, and health, and national nutrition is important for improving the nation's quality of life and the economy," and the 2025 Central 1 document calls for "promoting healthy eating, strengthening guidance for public dining establishments, and promoting the use of less oil, salt, sugar, and whole grains in meals."

Over the past four decades, China has made significant progress in the agricultural sector, increasing its total grain production from 3.05 billion tons to 6.95 billion tons in 2023, with an annual growth rate of 1.89%. The country's self-sufficiency rate for grains exceeds 95%, and for staple grains, it surpasses 100%. The average person's grain consumption exceeds 486.1

kilograms, surpassing the international threshold of 400 kilograms for food security.[1]

As food supplies increase, the dietary habits of Chinese residents are shifting from consuming grains and legumes to consuming oils and animal proteins (Liu et al., 2014). However, the issue of inadequate nutrition among rural residents remains significant. According to the 'China Residents' Report on the Nutritional Status and Chronic Diseases of Chinese Residents (2020), compared to urban residents, Chinese rural residents have lower income levels, limited access to food, and consume less diverse and lower quality grains, resulting in issues such as obesity, diet-related chronic diseases, and micronutrient deficiencies. The 7th National Population Census of China shows that 36.11% of the population live in rural areas, accounting for 5.1 billion people. Improving the dietary quality and nutritional status of Chinese rural residents has become an urgent issue.

Since the 21st century, China's internet development has achieved a leap forward, with big data, artificial intelligence, and other new digital technologies deeply integrating with the real economy. The country has entered a new stage of digital transformation in all areas of society. According to the China Internet Network Information Center (CNNIC) report, by 2024, China's internet user base reached 1.108 billion, with internet penetration at 78.6%. The digital economy surpassed 70 trillion yuan, establishing the world's largest digital consumer market. Alongside national digital transformation, the digitalization of agriculture and rural areas has also advanced significantly. Rural internet users now number 313 million, accounting for 28.2% of the total internet population. A cumulative total of 337,800 village-level integrated delivery and logistics service stations have been established, with online shopping penetration reaching 76.7%. People's lives and social production have been significantly impacted by the digital transition. Information technologies like the internet have had a significant impact on how all industries operate and produce. In the conventional economy, data, as a factor of production, propels the efficient integration and reorganization of labor, capital, and technology, leading to ongoing improvements in factor returns and allocation efficiency. In terms of day-to-day living, the quick growth of internet platforms has sped up the spread of information, significantly lowering the cost and difficulty of acquiring it. This has allowed people to access more important information and pick up new skills.

Given that nutritional issues among rural residents are primarily constrained by local food market size, geographical location, access to nutritional knowledge, and income levels, does digital transformation contribute to improving rural residents' nutritional status in both production and daily life? To address these questions, this study utilizes data from four rounds (2004, 2006, 2009, and 2011) of the China Health and Nutrition Survey (CHNS) to examine the impact of internet use on dietary diversity among rural residents. The research has two objectives: first, to empirically analyze whether internet use contributes to enhancing dietary diversity among China's rural population; and second, to elucidate the mechanisms through which internet use influences dietary diversity among rural residents.

The significance of this study manifests in two key dimensions. At the policy level, food and nutrition issues have long been integrated into agricultural policies and economic systems. Continuously improving the dietary structure of rural residents is both a natural extension and an inherent requirement of implementing the "comprehensive food security concept" and "building a diversified food supply system." By examining the mechanisms through which internet use impacts rural residents' nutrition, this research contributes to advancing the "comprehensive food security concept" and broadens the policy toolkit for enhancing rural nutrition, health, and sustainable development. Theoretically, the organic connection and theoretical mechanisms linking "internet use—farmers' production and daily life—nutritional improvement" have not received sufficient attention or in-depth exploration. This study contributes to revealing the underlying mechanisms of internet use on rural residents' nutritional improvement from both theoretical and empirical perspectives, thereby supplementing and enriching research on rural nutrition governance.

The remainder of this paper is organized as follows. Part 2 presents a literature review and theoretical analysis, summarizing research progress and gaps while constructing a household model to explain how internet use affects dietary diversity among rural residents. Part 3 outlines the research design, detailing data sources, variables, model specifications, and descriptive statistical analysis. Part 4 reports empirical findings, including benchmark regression analysis, endogeneity and robustness checks, heterogeneity analysis, and mechanism analysis results. The final section presents the conclusions and implications of the study.

2 Literature review and mechanism analysis

2.1 Literature review

Current research on rural residents' nutrition primarily focuses on measurement methods and influencing factors.

First, regarding nutritional status measurement, diverse methodologies exist. Among these, the Dietary Diversity Score (DDS) is widely adopted, as it better reflects changes in nutritional composition. Common approaches include nutrient intake levels, the Food Consumption Score (FCS) used by the United Nations World Food Program, and the Dietary Diversity Score (DDS) employed by the Food and Agriculture Organization (FAO). The core of the nutrient intake level method lies in measuring caloric intake, protein, and fat consumption. However, these indicators only reflect changes in nutrient quantities and cannot capture shifts in nutritional composition. The DDS and FCS share similar measurement mechanisms but differ slightly in food grouping, the food consumption recall period, and food group weighting. The choice of method depends on data collection timing, resources, and evaluator requirements.

Second, regarding the factors influencing rural residents' nutrition, these encompass both macro and micro factors. Among these, income is the primary factor, while other factors primarily exert their influence through income effects. At the macro level, rural nutrition is primarily affected by urbanization, market access, and agricultural production diversity. Urbanization continuously optimizes rural dietary consumption patterns by increasing non-agricultural income, reducing carbohydrate and fat intake, and

1 Data Source: China Food Security White Paper.

boosting protein consumption (Ren et al., 2021). Market access lowers transaction costs, increases farmers' sales revenue, and reduces expenses for agricultural inputs and food purchases, thereby enhancing household welfare and nutrition (Usman and Haile, 2022). Specialization reduces agricultural production diversity. In highly commercialized rural areas, production specialization can improve dietary diversity by increasing agricultural income, diminishing the importance of production diversification for dietary diversity. However, in less commercialized rural areas, production diversification remains crucial for dietary diversity (Ickowitz et al., 2019). At the micro level, the nutrition of rural residents is influenced by factors such as income level, education attainment, and nutritional knowledge. Zheng et al. (2023) found that nutrition education programs contribute to increased dietary diversity and total calorie intake among rural residents.

Against the backdrop of digital transformation, the internet—as a carrier and channel for information and digital technologies—has permeated rural production and living spaces with more advanced production methods, lifestyles, and concepts, profoundly impacting the "rural development-agricultural efficiency-farmer income" dynamic. Extensive research exists on the effects of internet use on the development of agriculture, rural areas, and farmers.

Some studies have examined the impact of internet development on residents' nutritional levels and quality, with differing perspectives emerging. On one hand, there are findings regarding the positive effects of internet usage on nutritional quality. Parlasca et al. (2020) examined the impact of mobile phone use on nutritional status in pastoralist communities in northern Kenya, finding that mobile phone use significantly enhanced dietary diversity. Twumasi et al. (2021) investigated the effects of internet use on food and nutrition security among rural households in Ghana, concluding that internet access improves household food availability (HFIAS) and dietary diversity, with more pronounced effects observed in households engaged in non-agricultural work and large-scale land management. Ma and Jin (2022) examined the impact of internet use on dietary quality among rural residents using CHNS (2006–2011) data. They found internet use increased China Food Pyramid scores by 10.4%. Leng et al. (2024) investigated the relationship between digital technologies, labor allocation, and nutritional intake using CFPS data. They discovered digital skills can boost rural residents' protein consumption by facilitating non-agricultural employment. On the other hand, regarding the negative impact of internet usage on nutritional quality, Zou and Lin (2024) examined the effect of takeout food consumption on overweight and obesity risks among urban residents. Their study found a direct correlation between frequent consumption of O2O takeout and increased risks of overweight and obesity. Liu et al. (2025) examined the impact of internet usage on adolescent nutrition. Their findings revealed that internet use increases protein intake while simultaneously leading to higher consumption of fast food and beverages, thereby elevating the risk of adolescent obesity.

This review identifies several areas warranting further exploration. Regarding research content, the mechanisms through which internet use affects rural residents' nutrition remain understudied. Domestic literature has not examined this topic, while only a few international studies touch upon it without fully investigating the underlying mechanisms linking internet use to rural nutrition. Regarding research indicators, existing studies on dietary diversity among rural residents primarily employ household-level dietary diversity scores (HDDS) as a proxy for nutrition. However, HDDS is not a highly precise indicator of dietary quality, as it overlooks intra-household food distribution issues. Individual dietary diversity scores (DDS) offer a more accurate measure of dietary quality (Parlasca et al., 2020). Furthermore, existing studies have not sufficiently discussed the heterogeneous effects of internet use on dietary diversity among rural residents. Based on this, this paper further expands the research on the aforementioned issues.

2.2 Mechanism analysis

Improvements in the nutritional status of rural residents primarily face obstacles such as income constraints, limited food accessibility, and insufficient nutritional literacy. Existing research has demonstrated that internet usage can enhance dietary diversity among rural residents by increasing market accessibility (Xue et al., 2021) and other means. Building upon prior studies, this research posits that the internet may also influence rural residents' nutrition through the following two pathways. Improving the nutritional status of rural residents primarily faces obstacles such as income constraints, limited food accessibility, and insufficient nutrition literacy. Existing research has demonstrated that internet usage can enhance dietary diversity among rural residents by increasing market accessibility and other means. Building upon prior studies, this research posits that the internet may also influence rural nutrition through the following two pathways.

In terms of direct effects, the internet can improve rural residents' dietary diversity by enhancing nutrition literacy. Nutrition literacy, a specialized form of health literacy, encompasses knowledge and concepts related to food nutrition, along with the skills required to obtain, select, and prepare food. It serves as a bridge connecting individuals, food, and their environment, playing a crucial role in dietary behavior change and improving dietary quality. Simultaneously, nutrition literacy primarily functions through nutrition education, profoundly influencing residents' ability to make scientifically informed nutritional decisions in both cognitive and skill-based dimensions. Traditionally, China's rural society has been structured around kinship and geographical ties, forming a social network system. Villagers' activities are constrained by three geographical boundaries: their living sphere, production sphere, and social sphere. Traditional customs and agrarian culture heavily influence dietary habits and patterns, often leading to a lack of rational understanding of dietary quality. Examples include eating "leftovers" due to thriftiness and preferences for staple foods with heavy oil and salt consumption stemming from high-intensity physical labor. Due to traditional beliefs and limited access to nutritional knowledge, nutritional literacy remains significantly underdeveloped. According to statistics from the National Health Commission, the health literacy rate among urban residents nationwide reached 33.25% in 2023, while that of rural residents stood at 26.23%, indicating a persistent gap in health literacy between urban and rural populations.

The widespread adoption of the internet has profoundly influenced and transformed rural residents' nutritional literacy and behavioral patterns. Generally speaking, rural residents acquire nutritional knowledge through two primary channels. First, they rely on mutual learning and imitation of nutritional knowledge among community members. However, within this model, the relatively closed nature of rural communities leads to limited and homogeneous sources of nutritional information. This approach has limited effectiveness in improving dietary quality, and the sharing of experiences within communities may even perpetuate numerous misconceptions about nutrition. Second, they acquire nutrition knowledge through traditional media such as television, radio, and newspapers. However, in these channels, rural residents are passive recipients of nutrition information. The nutrition knowledge disseminated by these official media often diverges significantly from the realities of rural life, making it difficult to generate an effective "demonstration effect." In contrast, internet communities leverage new media platforms like social networks for knowledge dissemination. Knowledge sharing is primarily driven by individuals who provide abundant scientific nutrition information and health advice closely aligned with rural residents' daily lives. This approach carries greater emotional resonance, readily forming a "demonstration effect" on rural residents' nutritional literacy and profoundly influencing their dietary perceptions and behaviors. Furthermore, rural residents can utilize search engines and other platforms to access cooking techniques and nutritional knowledge anytime, anywhere, according to their specific needs. This significantly enhances their nutritional literacy and improves dietary diversity. Based on the above discussion, the following hypothesis is proposed.

> *H1*: Internet use can enhance dietary diversity among rural residents through nutritional literacy.

In terms of indirect impact, internet use can improve nutritional levels by increasing rural household income. Building upon Barnum and Squire (1979) and Argaw et al. (2021), this paper analyzes the impact of internet use on dietary diversity among farming households within a semi-commercialized family farm behavior model framework featuring competitive labor markets. Semi-commercial farms represent a transitional model between fully commercial farms—which hire labor and sell all agricultural products—and purely subsistence farms—which rely solely on household labor and sell only a portion of their output. All households participate in the labor market as either buyers or sellers of labor. The fundamental assumptions of the Chinese agricultural model analyzed here align closely with this framework. Within this model, labor hours and output are determined by market wages and prices, both treated as exogenous variables.

Farmers aim to maximize utility under constraints, specifically production function constraints, time constraints, and budget constraints. To link this to dietary diversity, we assume separate utility functions for agricultural and non-agricultural goods, expressed as:

$$U = U\left(q_0, DD\left(q_1,\ldots,q_n\right);Z\right) \tag{1}$$

In Equation 1, U is the household utility function, $DD\left(q_1,\ldots,q_n\right)$ is defined as the sub-utility function for food consumption and also represents the consumption of non-agricultural goods (dietary diversity), q_0 denotes the consumption of agricultural products, and Z is the fixed household characteristic.

$$F = F\left(L, V_i; X\right) = 0 \tag{2}$$

In Equation 2, F is the production constraint function, L is labor input, V_i is other variable inputs, and X is the household structure characteristic.

$$Y = p_L T + pF - \sum v_i V_i - p_L L + E = p_0 q_0 + p_D DD \tag{3}$$

In Equation 3, Y represents total income, T denotes total available time, p_L, p, v_i, and p_L are the prices of various factors, p_0, p_D is the product price, and E is exogenous income.

Therefore, the relationship between farmers' demand for dietary diversity and various influencing factors can be further expressed as:

$$DD = h\left(p_0, p_D, Y, Z\right) \tag{4}$$

In Equation 4, dietary diversity is primarily influenced by product prices, household fixed characteristics, and income. Since product prices are exogenous and household fixed characteristics are constant, dietary diversity is mainly affected by income. Furthermore, the impact of the internet as an exogenous variable on dietary diversity is primarily transmitted through income. In traditional rural societies, farmers often face high and incomplete costs in accessing market information. The use of the internet plays a crucial role in reducing information asymmetry and transaction costs for farmers in areas such as agricultural input procurement, agricultural production, and agricultural product sales.

First, in the procurement of agricultural inputs, farmers traditionally rely on input dealers to purchase production factors, lacking diversity in procurement choices. The internet not only provides farmers with more procurement channels to obtain agricultural inputs at lower prices but also enables them to bypass distributors and purchase directly from manufacturers, securing even lower costs. Second, in agricultural production, the internet enhances total agricultural output by incorporating total factor productivity into production functions. It enables farmers to conveniently access critical production information such as pest forecasts and weather conditions, allowing more precise guidance on planting, fertilization, irrigation, and other processes. This reduces delays, losses due to missed planting seasons, and damages from weather disasters. Third, in the agricultural product sales phase, smallholder farmers in many developing countries typically sell their produce to middlemen between villages and markets. Farmers lack autonomous pricing power and can only passively accept prices. The internet not only helps narrow the gap in access to market price information for farmers, enabling them to understand price differences across markets and thereby improve bargaining power to raise agricultural product prices, but also helps farmers sell directly to consumers online, reducing distribution channels and granting them autonomous pricing power to increase sales prices. Based on the above discussion, the following hypotheses are proposed.

> *H2*: Internet use can increase farm household income, indirectly enhancing dietary diversity among rural residents.

3 Research design

3.1 Data sources

The data used in this study are selected from the China Health and Nutrition Survey (CHNS). This survey covers 15 provinces and municipalities: Beijing, Liaoning, Heilongjiang, Shanghai, Yunnan, Jiangsu, Henan, Hubei, Zhejiang, Hunan, Guangxi, Guizhou, Chongqing, and Shaanxi. To date, the CHNS official website has released data from 11 rounds of surveys conducted between 1989 and 2015. The survey employs a multistage, stratified, random sampling method, collecting information on socioeconomic status, individual dietary patterns and nutritional status, and household income. CHNS began collecting individual internet use data in 2004, and its food consumption and nutritional data are only updated through 2011. Therefore, this study selected data from four rounds (2004, 2006, 2009, 2011) as the sample dataset. First, nutritional data were matched with individual and household data. After retaining rural resident samples and cleaning missing values, an unbalanced panel dataset with a sample size of 27,012 was obtained. According to a report by the China Internet Network Information Center (CNNIC), internet penetration in rural areas rose from 0.076% in 2002 to 11.7% in 2008, reaching 20.7% by 2011. The rural internet usage sample in this study accounted for 15.1% of the total sample, which generally aligns with the rural internet penetration rates published by CNNIC. Considering the trend in internet penetration, the sample data still holds certain significance for current policy formulation.

3.2 Model specification

The benchmark regression model is specified in Equation 5:

$$DDS_{\text{it}} = \beta_0 + \beta_1 Internet_{it} + \beta_2 X_{it} + \sigma_t + \omega_i + \varepsilon_{it} \tag{5}$$

DDS_{it} denotes the dietary diversity score of rural resident i during the period t. $Internet_{it}$ represents the internet use status of rural resident i during period t, with a value of 1 for internet use and 0 otherwise. X_{it} denotes the control variables across three levels: individual characteristics, household characteristics, and community characteristics. σ_t and ω_i denote the time fixed effect and individual fixed effect, respectively. ε_{it} represents the random error term.

3.3 Variables and descriptive statistics

The dependent variable in this study is dietary diversity. Food types in the CHNS dietary data are classified and coded according to the Chinese Food Composition Table, divided into 21 major categories such as cereals and products, tubers, starches and products, and dried beans and products. A 6-digit coding system is used: the first three digits represent the food category code, the third digit indicates the food subcategory code, and the last three digits denote the sequential number within the subcategory. To calculate dietary diversity scores, this study combined the food classification standards of the Food and Agriculture Organization of the United Nations (FAO) and China's balanced diet pyramid, grouping the 21 major food categories into 9 categories: cereals, vegetables, fruits, meat, eggs, fish, dairy, nuts, and oils. The dietary diversity score is calculated based on the total number of distinct food categories consumed by each resident over a 3-day period. Each food category consumed is assigned a weighting of 1 point, with a maximum score of 9 points. Consumption frequency and quantity are not counted. Foods outside the above 9 categories—including infant formula, snacks, cookies, instant foods, beverages, sugar, dried fruits, candied fruits, and honey—are excluded from scoring.

The core independent variable in this study is whether or not individuals use the internet. Use of the internet is assigned a value of 1, and non-use is assigned a value of 0. Figure 1 presents the cumulative distribution of dietary diversity scores among rural residents in the internet-using and non-internet-using groups. It shows that the dietary diversity scores of the internet-using group are significantly higher than those of the non-internet-using group. Figure 2 illustrates the annual changes in dietary diversity scores among rural residents. Overall, dietary diversity scores exhibit a year-on-year increasing trend, with the internet-using group consistently maintaining higher scores than the non-internet-using group.

The control variables are based on the research of Huang and Tian (2019) and Deng et al. (2024), and include data from three levels: individual, family, and community. The individual-level variables are age and level of education. The level of education is calculated based on years of schooling. Those who did not attend school are assigned a value of 0, while those who graduated from elementary school are assigned a value of 6. Graduates of middle school are assigned a value of 9, graduates of high school (including general high school, technical school, and vocational school) are assigned a value of 12, graduates of college are assigned a value of 16, and graduates of graduate school are assigned a value of 19. The family-level variables are household size, household net income, whether or not the household owns a three-wheeled vehicle, a motorcycle, or a car, and whether or not the household owns a refrigerator. The community-level variables are urbanization rate and community population density.

Table 1 presents descriptive statistical analysis results. Regarding the dependent variable, the dietary diversity of the internet-using sample was approximately 1.286 higher than that of the non-internet-using sample. This mean difference passed the 1% significance test, preliminarily indicating that internet use positively promotes dietary diversity among rural residents. Regarding control variables, the mean differences between internet-using and non-internet-using samples all passed the 1% significance test, indicating the necessity of further controlling these variables in regression analysis.

4 Empirical analysis results

4.1 Benchmark regression results

Table 2 presents the results of the impact of internet use on dietary diversity among rural residents. Column (1) shows the univariate regression results. Controlling for individual fixed effects, the coefficient for internet use is significantly positive at the 1% level, indicating that internet use significantly promotes dietary diversity among rural residents. Column (2) adds control variables to the univariate regression, and the coefficient for internet use remains significantly positive at the 1% level. Column (3) controls for time fixed effects and other variables on top of the univariate regression. The coefficient for internet use remains significantly positive at the 1% level. The final column simultaneously controls for individual and time fixed effects, yielding robust regression results. These findings align with the conclusions of the studies by Deng et al. (2024) and Yang et al. (2023).

Among the control variables, when controlling for both individual and time fixed effects, the coefficients for household size and motorcycles are significantly positive at the 5% level. Specifically,

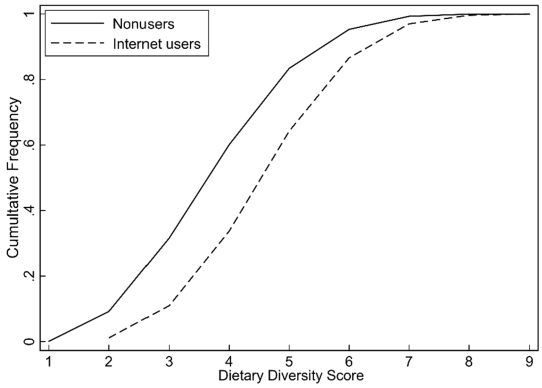

FIGURE 1
Cumulative distribution of dietary diversity scores among rural residents.

larger households may exhibit greater dietary diversity due to differing preferences among members. Motorcycles, as transportation tools, can shorten the distance between rural households and nearby markets or farmers' markets, thereby indirectly enhancing dietary diversity. Compared to other modes like tricycles or cars, motorcycles offer lower travel costs. The coefficients for refrigerators and household income were significantly positive at the 1% level, indicating that these variables exert a significant positive influence on rural residents' dietary diversity. Income stands as one of the primary factors enabling dietary diversity among rural residents, primarily by alleviating budget constraints. Karlsson and Subramanian (2023) note that refrigerator use mitigates nutrient loss in food, reduces exposure to harmful pathogens from improper storage, and enables purchasing larger quantities of food to improve nutrition while lowering costs.

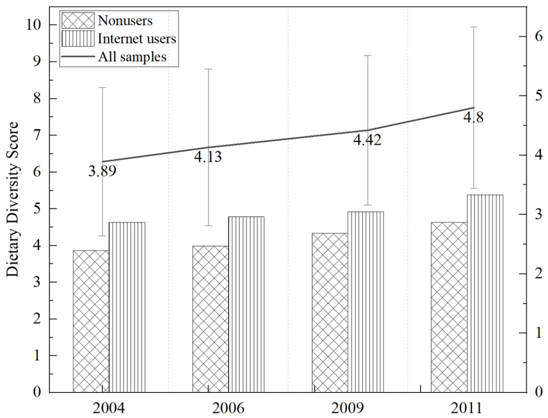

FIGURE 2
Annual trends in dietary diversity scores among rural residents.

4.2 Robustness analysis

4.2.1 Controlling for multidimensional fixed effects

To eliminate the influence of unobservable factors at the household and community levels, this study further controlled for household*year fixed effects and community*year fixed effects, allowing for differences in the intensity of individual responses to time shocks across communities and households. Column (1) of Table 3 shows that after controlling for multidimensional fixed effects, the coefficient for internet use remains significantly positive.

4.2.2 Removal of extreme outliers

During the sample period, internet users constituted approximately 17.79% of the total sample. Notably, internet users in 2004 accounted for 3.89% of the total sample, exhibiting significant divergence from the overall distribution. Based on this, the 2004 sample was excluded, and the benchmark model was re-tested.

TABLE 1 Descriptive statistics.

Variables	All samples		Non-internet users		Internet users group		Mean difference
	N = 27,012		N = 22,932		N = 4,080		
Dietary diversity	4.340	1.347	4.210	1.316	5.067	1.286	−0.857***
Age	45.440	17.990	47.660	17.570	32.980	14.990	14.678***
Level of education	6.494	4.516	5.999	4.316	9.273	4.605	−3.273***
Household size	3.909	1.651	3.889	1.678	4.020	1.487	−0.130***
Tricycle	0.155	0.362	0.165	0.371	0.099	0.299	0.065***
Motorcycle	0.398	0.489	0.391	0.488	0.438	0.496	−0.048***
Automobiles	0.078	0.269	0.060	0.237	0.183	0.387	−0.123***
Refrigerator	0.538	0.499	0.490	0.500	0.803	0.398	−0.313***
Household income	9.635	1.505	9.521	1.500	10.280	1.368	−0.758***
Urbanization rate	59.470	18.270	57.310	17.620	71.630	17.090	−14.318***
Community population density	5.699	1.312	5.615	1.292	6.168	1.323	−0.553***

Column (2) of Table 3 shows that the estimation results after excluding the extreme sample remain consistent with the benchmark regression results.

4.2.3 Testing with a different dependent variable

In the benchmark regression, the dependent variable defined dietary diversity for rural residents into 9 major categories. To further test the stability of the results, dietary diversity was categorized into 12 major groups: cereals, tubers, vegetables, fruits, meat, eggs, aquatic products, nuts, dairy, oils, sugars, and miscellaneous items. Column (3) in Table 3 shows that the estimation results after changing the dependent variable remain consistent with those from the baseline regression.

4.2.4 Test for variable substitution

To mitigate the inherent limitations of binary indicators in capturing behavioral variation, the independent variable was replaced with internet usage time. This variable represents the total time spent online from Monday to Sunday, with the data log-transformed. Column (4) in Table 3 shows that the coefficient for internet usage time remains significantly positive, indicating robust estimation results.

4.3 Endogeneity analysis

Although this paper controls for individual, household, and community-level covariates in the benchmark regression model and incorporates fixed effects for both individuals and time to address unobservable factors, endogeneity issues may still arise. First, unobserved variables are unavoidable. Second, rural residents' internet use may exhibit sample self-selection due to differences in individual, household, and community characteristics. To address these issues, this study primarily employs the instrumental variables method and the Heckman two-step approach.

4.3.1 Instrumental variables approach

This section employs household computer ownership as an instrumental variable for internet usage. On one hand, computer ownership is a prerequisite for internet access, and the two variables exhibit strong correlation, satisfying the relevance requirement for instrumental variables. On the other hand, computer ownership primarily reflects preferences for electronic information products and does not directly influence dietary diversity, meeting the exogeneity requirement for instrumental variables. Column (1) and Column (2) of Table 4 present the results of the first and second stages of the instrumental variable analysis, respectively. The coefficient in the first stage is positively significant at the 1% level, indicating a significant positive relationship between household computer ownership and internet usage. Additionally, the F-value of 59.51 in the first stage exceeds the empirical value of 10, confirming the absence of weak instrumental variable issues. The results of the second stage of the instrumental variable regression show that the coefficient for internet usage is significantly positive at the 5% level, consistent with the results of the baseline regression. This indicates that the estimated results remain robust after overcoming the endogeneity issue.

4.3.2 Heckman two-step method

The Heckman two-step method requires constructing an exclusion variable that influences only the selection probability in the first stage but is unrelated to the dependent variable in the second stage. In the first stage, the instrumental variable from the preceding analysis is reused as the exclusion variable. In the second stage, the inverse Mills ratio (IMR) estimated from the first stage is incorporated into the regression. In Heckman's first stage, the coefficient of the instrumental variable is significantly negative at the 1% level, indicating the selection of the exogenous variable is reasonable. In Heckman's second stage, the coefficient of the IMR is significantly negative at the 1% level, indicating the presence of sample self-selection. Simultaneously, the coefficient for internet use indicates that the estimation results remain robust after overcoming the sample self-selection issue.

4.4 Heterogeneity analysis

The socio-ecological framework emphasizes the complexity of food behavior and the interaction of individual and environmental factors in various circumstances (Story et al., 2008). Individual factors

TABLE 2 Baseline regression.

Variables	(1)	(2)	(3)	(4)
	DDS	DDS	DDS	DDS
Internet use	0.279*** (8.144)	0.172*** (5.116)	0.242*** (10.451)	0.165*** (4.855)
Age		0.087*** (24.561)	−0.002*** (−5.393)	−0.010 (−0.229)
Level of education		0.005 (1.154)	0.014*** (8.140)	0.005 (1.112)
Household size		0.019** (2.188)	−0.029*** (−6.142)	0.019** (2.164)
Tricycle		0.024 (0.781)	0.021 (1.029)	0.025 (0.790)
Motorcycle		0.054** (2.256)	0.115*** (7.283)	0.058** (2.409)
Automobiles		0.002 (0.046)	0.106*** (3.702)	−0.004 (−0.084)
Refrigerator		0.158*** (6.477)	0.334*** (19.287)	0.154*** (6.299)
Household income		0.044*** (6.178)	0.121*** (21.497)	0.044*** (6.172)
Urbanization rate		0.002 (1.184)	0.016*** (30.340)	0.002 (1.368)
Community population density		0.024 (1.191)	0.043*** (6.584)	0.022 (1.078)
Individual fixed effects	YES	YES		YES
Time fixed effects			YES	YES
_cons	4.298*** (830.570)	−0.520*** (−2.885)	1.646*** (25.555)	3.528** (1.969)
R^2	0.005	0.092	0.228	0.093
Observation	27,012	27,012	27,012	27,012

The value in parentheses is the *t*-value. ***, **, and * indicate significance at the 1, 5, and 10% levels, respectively. The same applies to the following tables.

TABLE 3 Robustness test.

Variables	(1)	(2)	(3)	(4)
	DDS9	DDS9	DDS12	DDS9
Internet use	0.077** (2.012)	0.203*** (5.217)	0.187*** (4.996)	
Internet usage time				0.038*** (5.279)
Control variables	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
Household*Time fixed effects	YES			
Community*Time fixed effects	YES			
_cons	2.724 (1.347)	3.924* (1.736)	2.327 (1.185)	3.308* (1.827)
R^2	0.741	0.071	0.088	0.093
Observation	22,315	21,108	26,458	26,791

Due to space limitations, the results of the controlled variable regression are not reported here. Interested parties may request them from the authors. The same applies to the following sections.

TABLE 4 Endogeneity tests.

Variables	(1)	(2)	(3)	(4)
	IV Phase I	IV Phase II	Heckman Stage I	Heckman Stage II
Internet use		0.397** (0.161)		0.155*** (0.034)
Instrumental variables	0.186*** (0.010)		0.938*** (0.028)	
IMR				−0.069** (0.042)
Control variables	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
_cons	2.403 (0.458)	2.959 (1.845)	−1.736 (0.103)	3.681 (1.796)
Observations	27,006	27,006	27,006	27,006

include biological and demographic characteristics, as well as behavioral abilities. Food affordability, availability, accessibility, and quality are all aspects in the food environment (Lytle and Sokol, 2017). Food affordability considers household income and the ability to purchase food; food availability considers the availability of food channels in the community; food accessibility also considers geographical distance and the cost of obtaining food; and food quality primarily considers the richness and variety of food types. According to the preceding discussion, the impact of internet use on dietary diversity among rural residents may range depending on individual, family, and community variables, as well as food type. As a result, this section focuses on heterogeneity from the perspectives outlined below.

4.4.1 Considering individual heterogeneity

Given the potential heterogeneity in the impact of internet usage on dietary diversity across different genders, ethnicities, and skill groups—due to variations in usage purposes, literacy, and capabilities—the total sample was segmented into distinct groups based on individual characteristics. The high-skill and low-skill groups were categorized based on whether the sample individuals had received high school education. Table 5 presents the test results for individual heterogeneity. In columns (1) and (2), the coefficients for internet use were significantly positive at the 1% level, and there was no significant difference in the magnitude of the coefficients between the two groups. Column (3) shows a statistically significant positive coefficient for internet use at the 1% level, while Column (4) shows a non-significant coefficient. These results indicate that internet use significantly influences dietary diversity among Han rural residents but has no significant effect on ethnic minority rural residents; Column (5) shows a coefficient for internet use that is significantly positive at the 1% level, while Column (6) shows a coefficient that is not significant. These results indicate that internet use has a more significant impact on dietary diversity among highly skilled rural residents compared to low-skilled rural residents.

4.4.2 Consider household heterogeneity

Given the differences in dietary patterns and lifestyles among households of varying incomes and sizes, the impact of internet usage on dietary diversity exhibits heterogeneity. Based on household characteristics, the overall sample was divided into low-income and high-income households according to median household income. The total sample was further divided into small households and medium-to-large households based on median household size. Table 6 presents the results of the household heterogeneity test. The coefficients for internet use in columns (1) and (2) are both significantly positive at the 1% level, indicating that internet use has a significant positive effect on both high-income and low-income households, with no significant difference in the magnitude of the coefficients between the two groups. Columns (3) and (4) show that the coefficients for internet use are both significantly positive at the 1% level, indicating that internet use has a significant positive effect on both small households and medium-to-large households, and there is no significant difference in the magnitude of the coefficients between the two groups.

4.4.3 Considering community heterogeneity

Given the varying accessibility of food markets across different regions, internet usage exerts heterogeneous effects on dietary diversity. Based on community characteristics, the total sample was divided into township and non-township groups according to whether they belonged to townships. The total sample was further divided into high-density and low-density communities based on median community population density. Table 7 presents the results of the community heterogeneity test. In Column (1), the coefficient for internet use is significantly positive at the 1% level, while in Column (2), the coefficient is not significant. This indicates that internet use significantly influences dietary diversity among rural residents in non-township areas but has no significant effect in township areas. The coefficients in columns (3) and (4) are significantly positive at the 5 and 1% levels, respectively, and the magnitudes of the coefficients differ significantly between the two groups. This indicates that internet use exerts a more pronounced positive effect on rural residents in low-density communities.

4.4.4 Considering food source heterogeneity

Given the diversity of online food supply types, internet usage exerts heterogeneous effects on dietary diversity. Based on nutritional knowledge, the total sample was divided into two groups: plant-based and animal-based foods. Plant-based foods primarily include grains, vegetables, fruits, and nuts, while animal-based foods include meat, dairy products, eggs, etc. Table 8 presents the results of the heterogeneity test for food source. In column (1), the coefficient for internet use is not statistically significant. In column (2), the coefficient for internet use is significantly positive at the 1% level, indicating that internet use has a significant positive effect on the dietary diversity of animal-source foods among rural residents, but no significant effect on the dietary diversity of plant-source foods.

4.5 Mechanism analysis

The theoretical analysis section indicates that internet usage influences dietary diversity among rural residents through both direct and indirect pathways. First, via the direct pathway, the internet can improve the nutritional environment by enhancing nutritional literacy. Nutrition literacy is measured using a proxy variable—whether individuals are aware of the Dietary Guidelines for Chinese Residents. Indirectly, internet use enhances nutritional status by increasing rural household income. The impact of household income on dietary diversity has already been validated in the baseline regression section and is not revalidated here. Table 9 presents the results of the mechanism analysis. Columns (1) and (2) validate the direct pathway mechanism. In Column (1), the coefficient for internet usage is significantly positive at the 1% level, indicating that internet usage has a significant positive impact on rural residents' dietary knowledge. In Column (2), even after controlling for dietary knowledge, internet usage still exerts a significant positive effect on dietary diversity. These

TABLE 5 Heterogeneity analysis: individual heterogeneity.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Male	Female	Han Chinese	Ethnic Minority	Highly Skilled	Low-skilled
Internet use	0.155*** (3.273)	0.177*** (3.652)	0.165*** (4.572)	0.132 (1.313)	0.196*** (4.724)	0.065 (0.933)
Control variables	YES	YES	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES
Intergroup coefficient difference	−0.022 (p = 0.340)		0.034 (p = 0.460)		0.132 (p = 0.110)	
_cons	5.065** (2.062)	1.980 (0.758)	3.255* (1.684)	5.470 (1.127)	2.933 (1.458)	1.115 (0.255)
R^2	0.096	0.091	0.087	0.139	0.096	0.081
Observation	13,119	13,893	23,121	3,891	22,350	4,662

TABLE 6 Heterogeneity analysis: Household heterogeneity.

Variables	(1)	(2)	(3)	(4)
	Low-income households	High-income households	Small families	Medium-to-large families
Internet use	0.203*** (2.694)	0.153*** (3.323)	0.186*** (3.497)	0.134*** (2.768)
Control variables	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
Intergroup coefficient difference	0.050 (p = 0.440)		0.052 (p = 0.360)	
_cons	2.029 (0.740)	4.876* (1.658)	2.800 (0.769)	2.063 (0.913)
R^2	0.105	0.092	0.082	0.093
Observation	13,491	13,521	12,097	14,915

TABLE 7 Heterogeneity analysis: community heterogeneity.

Variables	(1)	(2)	(3)	(4)
	Non-township areas	Township areas	High-density communities	Low-density communities
Internet use	0.278*** (6.258)	0.007 (0.143)	0.104** (2.360)	0.265*** (4.638)
Control variables	YES	YES	YES	YES
Individual fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
Intergroup coefficient difference	0.271 (p = 0.000)		−0.161 (p = 0.040)	
_cons	2.911 (1.478)	4.124 (1.009)	4.241 (1.524)	1.475 (0.587)
R^2	0.103	0.072	0.058	0.131
Observation	20,371	6,641	12,196	14,816

findings suggest that internet usage improves dietary diversity among rural residents by enhancing dietary knowledge and household income.

5 Research findings and implications

Nutrition issues among rural residents have long been a key concern in development economics. Health problems stemming from inadequate and imbalanced nutrition pose serious threats to the physical and mental well-being, quality of life, and productivity of rural populations. Continuously improving the nutritional health status of rural residents not only embodies the implementation of the "comprehensive food security concept" in the new era but is also an essential requirement for shifting the focus of food security from quantity to nutrition. Since the 18th CPC National Congress, strategic initiatives such as poverty alleviation and rural revitalization have steadily raised rural incomes, improved consumption patterns and living standards, and gradually enhanced nutritional health. Nevertheless, challenges persist, including coexisting malnutrition and overconsumption, high prevalence of nutrition-related diseases, and limited adoption of healthy lifestyles. Based on the above context, this study examines the effects of internet use on rural residents' dietary diversification experimentally using data from the China Health and Nutrition Survey (CHNS).

This study examines the impact of early internet adoption on the nutrition of rural residents. A key finding reveals a significant positive correlation between internet use and dietary diversity among these individuals. However, these effects exhibit heterogeneity. Firstly, internet use has a significant positive impact on the dietary diversity of Han Chinese rural residents and highly skilled individuals, but no significant impact on ethnic minorities and low-skilled individuals. These groups may not benefit from digitalization due to insufficient human capital, leading to limitations in their ability to retrieve and discern dietary information. Secondly, internet use has a significant positive impact on the dietary diversity of rural residents in non-township areas, but no significant impact in township areas. Furthermore, the impact is more significant in low-density communities than in high-density communities. This may be because non-township and low-density communities have more developed food market infrastructure and higher food accessibility compared to township and high-density communities, thus reducing their reliance on internet-based dietary improvements. Finally, internet use has a significant positive impact on the dietary diversity of animal-based foods among rural residents, but no significant impact on plant-based foods. This may be because internet food supply primarily focuses on easily preserved animal-based foods. In terms of mechanisms, internet use can improve the dietary diversity of rural residents through both direct means of enhancing nutritional literacy and indirect means of increasing household income.

According to the study's findings, the nutritional structure of rural residents can be improved by the internet as a digital technology from a "techno-social" standpoint. However, it is essential to highlight the "uneven" effects of internet use on the nutritional structures of various groups. With the increasing usage of AI-powered products, it is crucial to monitor and stop the "digital divide" from causing nutritional disparities to worsen. The following policy proposals are put forth in this study as a result. To begin with, the internet should be used as a crucial policy tool to improve dietary diversity among rural residents within the framework of digital rural development. On the one hand, it is crucial to keep improving internet infrastructure. Rural residents can be encouraged to transition from subsistence-oriented consumption to development-oriented consumption by enhancing the internet's ability to generate revenue and stimulate demand. This shift will gradually improve their nutritional compositions and increase the degree of dietary variety. On the other hand, relying on the Internet to provide high-quality digital resources and services for nutrition education, popularize new consumption concepts and dietary nutrition knowledge, helps to reverse the adverse effects of the concept of "excessive thrift" on health, and continuously promotes the formation of healthy eating habits among rural residents. In addition, the digital literacy of rural residents should be enhanced. In accordance with the digital economy's development trend, and taking into account the fact that rural residents are primarily elderly and low-income, low-skilled groups, provide policy support and training in computer and mobile phone internet skills, e-commerce platforms, mobile payment, and other digital tools, and continuously improve rural residents' ability to learn and use the internet. Last but not least, attention should be paid to the potential and role of the internet in driving nutritional transformation among key regions and groups. For rural communities characterized by low population density and remoteness from central towns, inclusive internet promotion policies should be formulated to reduce the cost of internet usage, thereby providing foundational support for expanding farmers' income channels and facilitating nutritional structural transformation.

TABLE 8 Heterogeneity analysis: food source heterogeneity.

Variables	(1)	(2)
	Plant-based food sources	Animal-derived foods
Internet use	−0.018 (−0.521)	0.113*** (3.037)
Control variables	YES	YES
Individual fixed effects	YES	YES
Time fixed effects	YES	YES
Intergroup coefficient difference	−0.131 (p = 0.020)	
_cons	3.317** (1.972)	9.777*** (4.601)
R^2	0.054	0.043
Observation	15,189	11,823

TABLE 9 Mechanism analysis.

Variables	(1)	(2)	(3)
	Nutrition knowledge	DDS	Household total income
Internet use	0.042*** (3.778)	0.159*** (4.449)	0.066* (1.715)
Dietary knowledge		0.053* (1.740)	
Control variables	YES	YES	YES
Individual fixed effects	YES	YES	YES
Time fixed effects	YES	YES	YES
_cons	3.049*** (5.482)	2.472 (1.274)	7.575*** (3.691)
R^2	0.061	0.091	0.124
Observation	25,416	25,416	27,012

While our study revealed a correlation between internet use and nutrition among rural residents, several limitations remain. All data in this paper are from the micro-level. Although endogeneity was tested using household computer ownership as an instrumental variable for internet use, it cannot be proven to be entirely exogenous due to its close correlation with income, education, lifestyle modernization, and information processing capabilities. Therefore, using internet promotion policies as exogenous variables and the latest survey data would help generalize the findings. Furthermore, we conducted heterogeneity tests across individuals, households, communities, and food sources, which helps examine the varying impacts of internet use but inevitably leads to over interpretation. Future research should consider these limitations.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://chns.cpc.unc.edu/data/datasets/, Household- and Individual-Level Data.

Author contributions

FY: Conceptualization, Methodology, Writing – original draft. DZ: Data curation, Formal analysis, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work 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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