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ORIGINAL RESEARCH

Analysis of the Coupled Coordination of Digital Economy and Public Health Services in China and Its Influencing Factors

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Background: The coordinated development of the digital economy and public health services is essential for integrating the "Digital China" and "Healthy China" strategies and accelerating the modernization of the public health system. However, substantial regional disparities persist, necessitating a systematic evaluation of the coupling and coordination between these two domains, along with the identification of key influencing factors to support evidence-based policymaking.

Methods: This study utilizes panel data from 30 Chinese provinces spanning 2012–2021. The entropy-weighted Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method is employed to quantify the levels of digital economy development and public health services. A coupling coordination model is employed to evaluate the degree of coordinated development between these sectors, whereas a panel Tobit model serves to identify the key influencing factors.

Results: The overall trajectory of China's digital economy and public health services exhibits an upward yet fluctuating trend. The degree of coupling coordination has progressed from a state of near imbalance to a marginally coordinated phase, although it remains relatively low. Spatially, the eastern regions exhibit a higher degree of coordination, whereas the central and western regions primarily experience imbalances characterized by a lagging digital economy. Furthermore, the coupling coordination degree demonstrates a significant spatial positive correlation. Economic development is identified as the primary driver of improved coordination, whereas factors such as population density and health status exert inhibitory effects to some extent.

Conclusion: To enhance overall coordination and achieve regional balance, policymakers should tailor development strategies to local resource endowments, optimize the synergy between the digital economy and public health services, and refine collaborative mechanisms.

Keywords: digital economics, public health services, coupled coordination, influencing factors, Tobit model

Introduction

Effectively, equitably, and efficiently allocating public health services is essential for safeguarding residents' health, responding to public health emergencies, promoting social equity, and driving national socioeconomic development.[1] However, China's public health service system continues to face multiple challenges, including insufficient integration of service frameworks, imbalances and inadequacies in service quality, and constraints on the roles played by technical professionals and relevant administrative departments.[2] To address these issues more effectively, in 2024, the National Development and Reform Commission of China introduced the Implementation Plan for Promoting Common Prosperity through the Digital Economy, which explicitly advocates leveraging the digital economy to mitigate disparities and deficiencies in essential public services. The plan aims to enhance the accessibility and equitable distribution of public health services, ensuring that individuals not only benefit from the dividends of the digital era but also experience an improved quality of life.[3] Consequently, a pressing challenge remains: how to foster the coordinated development of the digital economy and public health services to provide residents with balanced and efficient public health resources.

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Existing research suggests that the digital economy can significantly reduce the cost of public health services and enhance service quality by fostering technological innovation, optimizing resource allocation, and improving data governance capabilities.[4] GUAN X highlighted that the widespread application of digital technologies not only optimizes the distribution of healthcare resources but also helps narrow disparities in health services across different regions and population groups.[5] Similarly, SCHWAMM's study found that the digital economy facilitates advancements in medical informatization, smart healthcare devices, and telemedicine, thereby improving the overall standard of public health services.[6]

Furthermore, Li et al employed a mediation effect model to examine the impact of the digital economy on urban public health and concluded that the digital economy significantly enhances urban public health outcomes while exhibiting a certain degree of spatial spillover effect.[7] Additionally, the application of digital technologies in the public health sector—such as visual data dissemination, mobile health management, and intelligent healthcare systems—has been instrumental in enhancing healthcare coordination and service efficiency.[8] Meanwhile, the digital economy also strengthens public health governance by enhancing government regulatory capabilities and optimizing governance structures, thereby reinforcing the role of healthcare professionals and relevant institutions in the provision of public health services.[9]

Although existing studies have extensively explored how the digital economy drives public health services, most have focused on unidirectional impacts while overlooking the bidirectional coupling and coordination between the two. In reality, public health services not only serve as a critical application domain for the digital economy but also actively contribute to its development. First, the modernization demands of public health systems have stimulated research and applications of digital technologies, such as medical big data, telemedicine, and AI-based diagnostics, thereby accelerating the growth of the digital health industry.[10] Second, the accumulation and accessibility of health data provide essential resources for the digital economy, facilitating the expansion of the digital platform economy.[11] Additionally, government investments in the digitalization of public health systems have stimulated the growth of health technology enterprises, fostering emerging industries such as smart healthcare and digital health management, which, in turn, further propel the development of the digital economy.[12] Therefore, this study systematically examines the coupling and coordination mechanisms between the digital economy and public health services, quantifies their degree of coupling coordination, and further explores the key factors influencing their coordinated development to propose targeted policy recommendations.

Therefore, this study systematically examines the coupling and coordination mechanisms between the digital economy and public health services, quantifies their degree of coupling coordination, and further explores the key factors influencing their coordinated development to propose targeted policy recommendations. The marginal contributions of this study are as follows: Theoretical Contribution:1. Theoretical Contribution: This study expands the theoretical framework of the synergistic development of the digital economy and public health services by systematically elucidating their bidirectional interaction mechanisms. 2. Empirical Contribution: By employing empirical models and exploratory spatial data analysis, this study identifies regional disparities in the coupling coordination between the digital economy and public health services, providing data-driven insights for policy optimization.

Theoretical Mechanism

The theory of coupling and coordination contains two key concepts: "coupling" and "coordination". Coupling refers to the mutual influence and interdependence between systems, ie, two or more systems interact through dynamic associations, which are not only unidirectional but have a continuous two-way influence. Coordination, on the other hand, emphasizes the transfer and conversion of matter, information and energy between systems, ultimately achieving benign interaction and symbiotic development.[13] Leveraging the theoretical framework of coupling coordination, the interplay between the digital economy and public health services is conceptualized as a dynamic process in which both systems mutually support and influence each other.[14] With the help of the coupling coordination theory, the coupling coordination problem of digital economy and public health service is regarded as an interactive process of two systems supporting and influencing each other. There exists a close coupling and coordination relationship between the digital economy and public health service systems, and the two, through interaction, jointly promote the efficient, intelligent and sustainable

development of public health. The digital economy serves as a technological enabler for achieving the equitable distribution of public health services, while the efficient delivery of public health services generates favorable market demand and fosters an enabling environment for the advancement of digital technologies. Through the mutual integration and reinforcement of these two systems, a virtuous cycle of interactive development gradually takes shape.

The Digital Economy Can Effectively Contribute to the Development of Public Health Services

The digital economy, underpinned by digital governance and supported by digital infrastructure, accelerates the innovation and application of digital technologies, thereby fostering the deep integration of industrial digitization and digital industrialization.[15] A review of the literature suggests that advancements in digital infrastructure effectively mitigate the spatial and temporal constraints of traditional healthcare services by facilitating the seamless cross-regional flow of capital, technology, and talent, ultimately optimizing the allocation of healthcare resources.[16] Simultaneously, as digital infrastructure continues to improve, the speed of information dissemination increases significantly, helping to reduce information asymmetry across regions. This enhancement not only facilitates the aggregation of supply and demand information within the public health service sector but also enables dynamic matching and precise alignment of healthcare resources, thereby accelerating resource circulation and lowering transaction costs associated with information asymmetry.[13] At the technological level, the widespread adoption of digital solutions—such as telemedicine, the Internet of Medical Things (IoMT), and electronic health records—has significantly improved the accessibility and quality of healthcare services while strengthening the overall supply capacity of the public health service system.[14] Additionally, the integration of the digital economy with traditional industries has fostered the emergence of new business models, injecting fresh momentum into the development of public health services. The cross-temporal and cross-spatial characteristics of the digital economy help bridge regional development disparities, while diverse digital financial tools expand financing channels for public health services and optimize their funding structures.[17,18] In the long term, the innovative application of digital technologies not only drives the advancement of public health services but also promotes the seamless integration of cutting-edge technologies—such as artificial intelligence (AI), blockchain, digital therapeutics, and predictive analytics—into the public health sector. This integration supports the upgrading and modernization of public health service infrastructure, further enhancing service quality and efficiency.[19] Moreover, the application of digital governance in public health services strengthens government decision-making transparency, enhances administrative efficiency, and improves regulatory effectiveness. Consequently, it fully leverages the role of specialized agencies in the public health sector, providing a robust institutional framework and a conducive environment for the high-quality development of public health services.[20,21] In summary, the digital economy empowers the public health service system through four key dimensions: infrastructure development, technological innovation, industrial integration, and digital governance. This multifaceted support optimizes service provision, balances resource allocation, and enhances governance capabilities, thereby accelerating the modernization of public health services.

Public Health Services Support the Promotion of High Quality in the Digital Economy

Enhancing the provision of public health services is essential for the sustainable development of the digital economy. In recent years, China has steadily increased its fiscal investment in the public health sector. In 2023, healthcare expenditures accounted for 7.2% of total fiscal spending, while central government allocations for basic public health service subsidies reached 72.53 billion yuan, representing an 8.7% year-on-year increase. This sustained financial support has accelerated the digitalization of public health services by driving the development of digital infrastructure and providing critical support for telemedicine, health big data applications, and other digital health initiatives.[22] Beyond improving public health outcomes, government investment in the public health system has laid a solid foundation for digital economic innovation, facilitating the digital transformation of the healthcare industry and fostering the deep integration of the digital economy with public health services. From a human capital perspective, investment in public health services ensures the delivery of higher-quality medical care, healthcare, and health management services, thereby contributing to the overall improvement of population health.[23] The accumulation of health-related human capital

directly influences labor market quality and productivity by supplying enterprises with a highly skilled workforce, fostering rapid digital economic growth through knowledge innovation and the creation of high value-added outputs.[24] Moreover, a healthier workforce enhances labor productivity, providing stable and efficient human resource support for the digital economy sector. In the long run, improvements in the quality of public health services will generate sustained human capital dividends, further driving economic and social progress. From an industrial linkage perspective, advancements in public health services have stimulated growth in related industries such as medical equipment manufacturing, pharmaceutical research and development, and health management.[25] The digital transformation of these industries provides the digital economy with diverse application scenarios and vast data resources, accelerating the adoption of emerging technologies—including artificial intelligence, big data analytics, and cloud computing—within the healthcare sector.[26] For instance, the rise of smart health devices, telemedicine systems, and digital health management platforms has not only enhanced the precision and accessibility of public health services but has also fostered the emergence of new digital economy business models, thereby contributing to regional economic growth.[27]

Overall, public health services and the digital economy exhibit a mutually reinforcing and interdependent relationship. On one hand, technological innovation and industrial integration within the digital economy propel the intelligent, precise, and equitable development of public health services. On the other hand, high-quality public health service provision strengthens social human capital, promotes industrial upgrading, and expands the application scope of digital technologies, thereby supporting the sustainable growth of the digital economy. This coupling mechanism not only enhances public health and societal well-being but also provides a new pathway for achieving equitable access to public health services in the digital era (Figure 1).

Materials and Methods

Selection of Indicators

Constructing Evaluation Indicators for the Digital Economy and Public Health Services

This paper adopts the entropy method to calculate the index of digital economy development level and draws on existing research,[28–32] to construct an evaluation index system of digital economy development level that includes 26 basic indicators in the dimensions of digital infrastructure, digital industrialization, industrial digitization, digital innovation and digital governance. Among them, digital infrastructure is the cornerstone of digital economy development, digital industrialization reflects the development level of industries relying on digital technology and data elements, industrial digitization measures the degree of integration between the digital economy and traditional industries, digital innovation reflects the investment in digitally related R&D personnel and R&D funding, and digital governance is the application of digital technology in government governance, reflecting the efficacy of the digital government in terms of governmental services. In terms of public health services, drawing on the indicator system established in relevant research,[33–35] the entropy value method is additionally employed to compute the development index of public health services. This is achieved by selecting 11 fundamental indicators across four dimensions: medical resource input, medical service output, health prevention services, and health protection services. Among them, the first two dimensions reflect the economic benefits of public health services, while the last two dimensions reflect their social benefits (Table 1).

Influencing Factors of Coupling and Coordination of Digital Economy and Public Health Services

There are various factors that affect the coupled and coordinated development of digital economy and public health services. Based on existing research and the availability of comprehensive indicator data, this paper analyses the key factors that may affect the development of the coupling of the two from a variety of aspects in combination with the actual situation in China, including government input, the level of economic development, the level of public health and the social development environment.[36,37] The following variables are finally selected as explanatory factors: government support, economic development level, population health level, population distribution density, technological innovation capacity, and human capital. Some of the data were processed by secondary calculation to ensure the accuracy of the results[8,9,12,38] (Table 2).

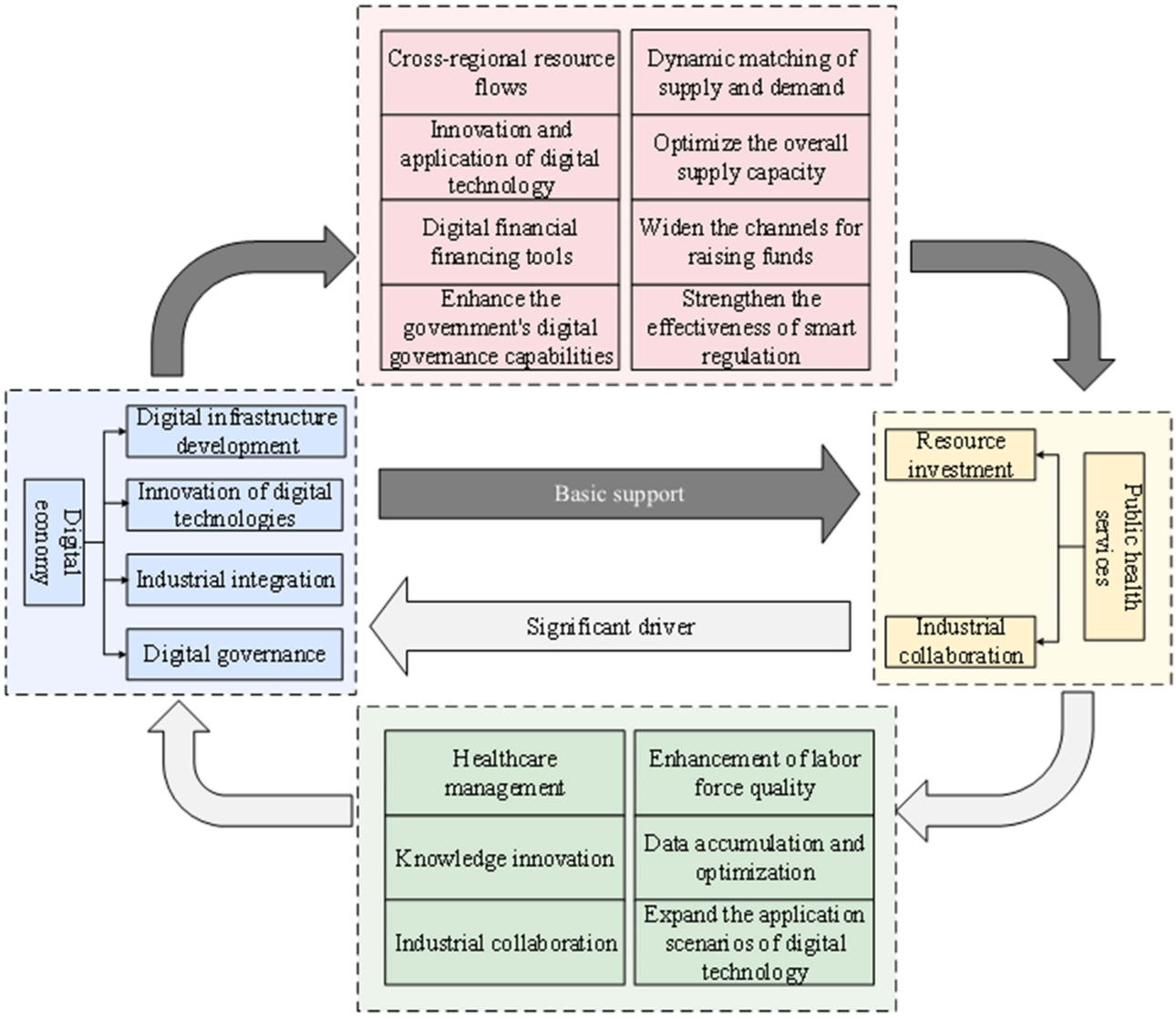

Figure 1 Theoretical model.

Research Methodology

Coupling Evaluation Model

In the coupling evaluation model, traditional coupling degree analysis can reveal the interactions between two systems; however, it has limitations in assessing the extent of their synergistic effects. Therefore, this study incorporates the coupling coordination index, treating the digital economy and public health services as two distinct systems. Based on this approach, a coupling coordination model for the digital economy and public health services is constructed,[30] as follow:

$$C = \frac{2\sqrt{U_1 U_2}}{(U_1 + U_2)}$$

$$D = \sqrt{C \times T}$$

$$T = \alpha U_1 + \beta U_2$$

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Table 1 A Collection of Indicators for Evaluating Inter-Provincial Public Health Services and the Digital Economy in China

Target System	Tier 1 Indicators	Tier 2 Indicators	Orientations
Essential Public Health Services	Medical resource input	Grassroots medical and health institutions per thousand people	+
		Number of beds in health institutions per thousand people	+
		Number of professional (assistant) physicians per thousand people	+
	Medical services output	Per capita total health expenses	+
		Resident hospitalization rate	+
		Maternal mortality rate	−
		Newborn visit rate	+
	Health prevention services	Incidence rate of Class A and B infectious diseases	−
		Premarital medical examination rate	+
		Women's disease examination rate	+
		Number of public health education activities per thousand people	+
	Health protection services	Medical insurance coverage rate	+
		Number of health examinations (person times per thousand people)	+
		The maternity insurance coverage rate	+
Digital Economy	Digital infrastructure	Broadband access ports for Internet use per 100 population	+
		Mobile phone penetration rate	+
		IPv4 addresses per 100 population	+
		Domain names per 100 people	+
		Web pages per 100 inhabitants	+
		Mobile phone base stations per 100 population	+
		Fibre optic cable route density	+
	Digital industrialization	Total telecommunication services per capita	+
		Percentage of employees in the information transmission, software industry	+
		Software product revenue per capita	+
		Software product revenue per capita operating income of electronic information manufacturing enterprises	+
		Number of manufacturing enterprises in the electronic information industry	+
		Number of enterprises in the software and information technology services industry	+
		Percentage of digital TV subscribers	+
	Industrial digitization	Percentage of employees in computer services and software	+
		Percentage of rural broadband access users	+
		E-commerce transactions per capita	+
		Computers per 100 population	+
		Websites per 100 enterprises	+
		Digital Inclusive Finance Index	+
	Digital Innovation	R&D expenditure on software and information technology services	+
		Software and information technology services R&D staff	+
		R&D personnel in the electronics and communications equipment manufacturing industry	+
		R&D expenditure on electronics and communications equipment manufacturing	+
		Internal expenditures	+
	Digital Governance	Government online government service capacity index	+

Where C is the degree of coupling, D is the degree of coupling coordination, T is the comprehensive evaluation index of the two systems, U1 and U2 are the evaluation values of public health services and digital economy, respectively; α and β are the coefficients to be determined, and they satisfy $\alpha = \beta = 0.5$,[39] which indicates that the public health services are equally important as the digital economy. To provide a more intuitive representation of the coupled and coordinated development between public health services and the digital economy across regions, this study draws on the relevant findings of Li[40] to classify the coordination levels of the two subsystems (Table 3).

Table 2 Factors Affecting the Coordinated Development of Coupled Digital Economy and Public Health Services

Variable Classification	Variable Name	Variable Symbol	Variable Description
Explained Variable	Coupling coordination degree	D	The results of the coupling coordination degree of two systems
Explanatory Variable	Government support	Gov	The proportion of government health expenditure in fiscal expenditure
	Economic development level	Led	per capita GDP
	Population distribution density	Pop	Population density = year-end population/whole province area
	Technology innovation level	TI	Share of R & D spending to GDP
	Human capital level	HC	Enrollment rate in higher education
	Health level of residents	MR	Population mortality rate = number of deaths/year-end population

Table 3 Coupling Coordination Evaluation Criteria

Coordination Type	Coupling Coordination Degree D Value Range	Coupling Coordination Degree
Disordered Decline	(0.0~0.1)	Extremely disordered
	(0.1~0.2)	Serious disorder
	(0.2~0.3)	Moderate disorder
	(0.3~0.4)	Mild disorder
Transitional Harmony	(0.4~0.5)	Nearly disorder
	(0.5~0.6)	Barely coordinated
Coordinated Development	(0.6~0.7)	Primary coordination
	(0.7~0.8)	Intermediate coordination
	(0.8~0.9)	Good coordination
	(0.9~1.0)	High-quality coordination

TOPSIS Entropy Weighting Method

TOPSIS entropy weight method objectively assigns weights according to the discrete degree of index data, avoiding the interference of human subjective factors on weight allocation, thus improving the scientificity and fairness of evaluation, which is suitable for solving the problem of multi-objective decision-making. Therefore, this paper adopts the entropy weight TOPSIS method to measure the development level of digital economy and public health services. The calculation process is as follows:

1. Assuming that there are m decision units (provinces and cities) and n evaluation indicators, the following decision matrix is constructed:

$$X = \begin{pmatrix} X11 & X12 & X13 & X14 & X15 & X1n \\ X21 & X22 & X23 & X24 & X25 & X2n \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ Xm1 & Xm2 & Xm3 & Xm4 & Xm5 & Xmn \end{pmatrix}$$

1. As different indicators may have different scales, the data need to be standardized as follows:

$$y_{mn} = \frac{X_{mn} - X_n^{min}}{X_n^{max} - X_n^{min}}$$

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1. Calculating the composite score:

$$P_{mn} = \frac{y_{mn}}{\sqrt{\sum_{m=1}^{m} y_{mn}^2}}$$

$$E_n = -K \sum_{m=1}^{m} f_{mn} \ln f_{mn}, f_{mn} = \frac{y_{mn}}{\sum_{m=1}^{m} y_{mn}}, K = \frac{1}{\ln m}$$

$$d_n = 1 - E_n$$

$$W_n = \frac{d_n}{\sum_{n=1}^{n} d_n}, 0 \le W_n \le 1 \sum_{n=1}^{n} d_n = 1$$

$$Z_m = \sum_{n=1}^{n} W_n P_{mn}$$

In this formula, P_{mn} is the nth indicator in the mth decision unit; information entropy value; E_n is information entropy value; W_n is indicator weights; Z_m is comprehensive evaluation value.

Tobit Panel Model

Since the degree of coupling coordination takes values between 0 and 1, it is a restricted dependent variable. Therefore, this paper uses the Tobit Panel Model to analyse the influencing factors of the degree of coupling coordination between the digital economy and public health services. To mitigate issues related to multicollinearity and heteroskedasticity, this study applies a logarithmic transformation to all explanatory variables. The corresponding calculation formula is as follows:

$$Y_{it} = \alpha_i + \sum_{j=1}^{m} \beta_j \ln X_{it} + \varepsilon_{it}$$

where Y_{it} is coupled co-scheduling; $\alpha_i$is a constant term; β_j represents the coefficients of each explanatory variable; $\ln X_{it}$ represents the explanatory variables; i and t represent province and time, and ε_{it} is a random perturbation term.

Data Source

This study selects data from 30 provinces, autonomous regions, and municipalities directly under the central government of China (excluding Tibet, Hong Kong, Macao Special Administrative Region, and Taiwan) for the period from 2012 to 2021. The data are primarily obtained from the China Statistical Yearbook, China Health Statistics Yearbook, and the statistical yearbooks and official websites of the respective provinces. Following the classification in the China Statistical Yearbook, the country is divided into eastern, central, and western regions for analysis.

Analysis of Results

Analysis of the Degree of Coupled Coordination between the Digital Economy and Public Health Services

As shown in Table 4, the average coupling coordination degree between the digital economy and public health services over the ten-year study period was 0.417, 0.428, 0.427, 0.409, 0.420, 0.437, 0.435, 0.432, 0.454, and 0.439, respectively, exhibiting a fluctuating yet generally upward trend. Overall, the coordination level improved from a state of near imbalance to the stages of primary and moderate coordination, with an average annual growth rate of 0.56% and a total increase of 2.17%. Specifically, the national average rose from 0.417 in 2012 to 0.439 in 2021, indicating that the enabling role of the digital economy in public health services has progressively strengthened, fostering deeper synergies

Table 4 Degree of Coupling and Coordination between Public Health Services and Digital Economy in China's Provincial Areas, 2012–2021

Region	Province	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Eastern	Beijing	0.84	0.92	0.92	0.83	0.84	0.92	0.84	0.93	0.84	0.83
	Tianjin	0.23	0.22	0.21	0.21	0.22	0.23	0.24	0.24	0.24	0.25
	Hebei	0.48	0.49	0.47	0.32	0.47	0.51	0.50	0.48	0.49	0.50
	Liaoning	0.51	0.51	0.50	0.47	0.50	0.50	0.47	0.44	0.44	0.43
	Shanghai	0.61	0.75	0.74	0.73	0.75	0.63	0.64	0.64	0.65	0.66
	Jiangsu	0.61	0.63	0.61	0.68	0.71	0.66	0.72	0.66	0.66	0.68
	Zhejiang	0.68	0.68	0.67	0.69	0.70	0.71	0.70	0.71	0.70	0.71
	Fujian	0.54	0.54	0.53	0.52	0.53	0.54	0.53	0.53	0.53	0.54
	Shandong	0.55	0.58	0.56	0.55	0.58	0.58	0.56	0.54	0.55	0.58
	Guangdong	0.80	0.81	0.79	0.79	0.78	0.81	0.80	0.78	0.76	0.75
	Hainan	0.21	0.21	0.21	0.21	0.21	0.23	0.23	0.22	0.22	0.23
Central	Shanxi	0.45	0.52	0.43	0.39	0.19	0.19	0.41	0.40	0.41	0.41
	Jilin	0.21	0.20	0.20	0.18	0.20	0.21	0.20	0.17	0.15	0.14
	Heilongjiang	0.40	0.41	0.43	0.39	0.42	0.20	0.18	0.17	0.16	0.12
	Anhui	0.13	0.14	0.15	0.15	0.17	0.40	0.41	0.41	0.43	0.43
	Jiangxi	0.27	0.30	0.34	0.32	0.34	0.39	0.39	0.36	0.38	0.39
	Henan	0.27	0.35	0.35	0.36	0.41	0.46	0.47	0.45	0.48	0.49
	Hubei	0.49	0.51	0.51	0.50	0.51	0.52	0.52	0.53	0.53	0.52
	Hunan	0.42	0.40	0.40	0.36	0.38	0.43	0.43	0.41	0.45	0.43
Western	Neimenggu	0.22	0.22	0.21	0.19	0.20	0.21	0.21	0.19	0.41	0.39
	Guangxi	0.37	0.36	0.34	0.32	0.32	0.36	0.40	0.36	0.48	0.38
	Chongqing	0.42	0.44	0.44	0.44	0.45	0.48	0.47	0.47	0.47	0.47
	Sichuan	0.50	0.55	0.55	0.58	0.59	0.61	0.60	0.60	0.62	0.61
	Guizhou	0.23	0.23	0.23	0.23	0.27	0.41	0.38	0.38	0.38	0.23
	Yunnan	0.32	0.37	0.36	0.36	0.37	0.44	0.38	0.38	0.46	0.27
	Shanxi	0.48	0.47	0.47	0.47	0.49	0.50	0.51	0.49	0.50	0.49
	Gansu	0.12	0.14	0.13	0.14	0.13	0.18	0.17	0.18	0.18	0.19
	Qinghai	0.43	0.18	0.39	0.18	0.18	0.21	0.21	0.19	0.41	0.38
	Ningxia	0.19	0.19	0.19	0.19	0.19	0.22	0.21	0.21	0.21	0.21
	Xinjiang	0.53	0.53	0.49	0.51	0.49	0.38	0.27	0.43	0.42	0.45

between the two systems. However, in terms of growth rate, the overall increase remains relatively modest, suggesting that the coupling coordination process is still constrained by multiple factors (Figure 2).

From a trend evolution perspective, the coupling coordination degree exhibited a slow upward trajectory from 2012 to 2014, reflecting the initial convergence phase of digital infrastructure development and public health digitalization. However, a slight decline was observed in 2015 (0.409), which may be attributed to several factors, including constraints on the widespread adoption of digital medical technologies, regional disparities in digital infrastructure development, and inefficiencies in healthcare resource allocation. Since 2016, the coupling coordination degree has generally followed an upward trend, with particularly significant growth between 2017 and 2020, peaking at 0.454 in 2020. This increase was primarily driven by the deepening implementation of the "Internet + Healthcare" policy, the growing penetration of digital technologies in public health management, and the accelerated development of telemedicine and digital health services in response to the COVID-19 pandemic.

From the perspective of regional phase distribution, the overall national level remains in the initial coordination stage, falling short of achieving widespread high-level coordination. Although certain regions have attained relatively higher coordination levels, the overall pattern is still characterized by low to moderate coordination, with significant regional disparities. At the regional level, from 2012 to 2021, the average coupling coordination degrees in the eastern, central, and western regions were 0.57, 0.36, and 0.34, respectively, with corresponding average annual growth rates of 0.61%, 3.24%, and 1.85%. Among these, the eastern region consistently maintained a "barely coordinated" status, exhibiting

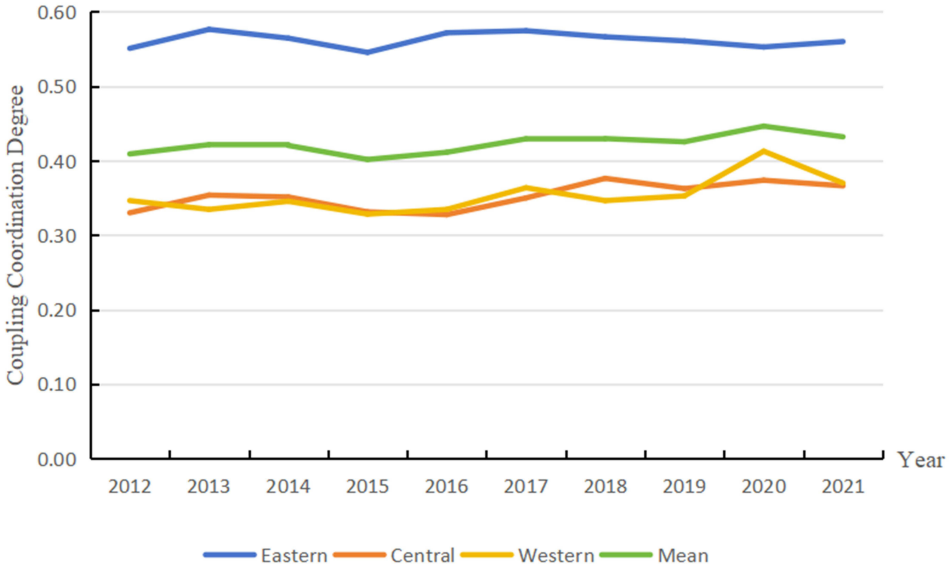

Figure 2 Trends in the degree of coordination of the coupling of the two systems in China's provinces and cities.

characteristics of transitional harmonization. Compared to other regions, the digital economy has exerted a more significant influence on the enhancement of public health services in the east. In contrast, although the coupling coordination degree in the central and western regions has improved over time, their overall levels remain below the national average, indicating persistent structural imbalances and inadequate adaptation.

At the city level, from 2012 to 2021, the coupling coordination degree between the digital economy and public health services across Chinese provinces exhibited significant regional disparities. Between 2019 and 2021, most cities witnessed a decline in coupling coordination, further intensifying regional development disparities. Moreover, the majority of cities continued to exhibit a state of "transitional harmonization".

Further comparative analysis reveals that only six provinces and municipalities, including Beijing, Shanghai, and Jiangsu, achieved the "coordinated development" stage during this period, with their coupling coordination degrees falling within the range of "primary coordination" to "good coordination" (Table 4). In terms of growth trends, some regions demonstrated significant progress, advancing from "transitional coordination" in 2012 to "primary coordination" in 2021. In contrast, the western region lagged behind overall, with only Sichuan Province reaching the "primary coordination" level by 2021, while most other areas remained in a state of "imbalance".

According to the spatial distribution of the coupling coordination level between the digital economy and public health services across different regions in China (Figure 3), significant spatial disparities in regional development coordination were observed from 2012 to 2021.

In 2012, the eastern and some central provinces had preliminarily entered the "primary coordination" or "good coordination" stage, whereas most western regions (eg, Tibet, Qinghai, Gansu) remained in a state of "imbalance". By 2016, the coupling coordination degree in certain central provinces (eg, Anhui, Henan, Jiangxi) had improved significantly, reflecting advancements in digital economy infrastructure and the integration of public health resources. Meanwhile, eastern coastal provinces (eg, Guangdong, Jiangsu, Zhejiang, Shandong) maintained relatively high levels of coupling coordination, though with limited growth.

By 2021, the coupling coordination degree in central provinces (eg, Anhui, Jiangxi) and parts of the southwestern region (eg, Sichuan, Chongqing, Guizhou) had further improved, with some areas advancing from the "transitional coordination" to the "primary coordination" stage. However, overall progress in the western regions (eg, Tibet, Qinghai, Gansu) remained slow, with most areas still in a state of "imbalance", underscoring the persistent disparities in the coordinated development of the digital economy and public health services across China.

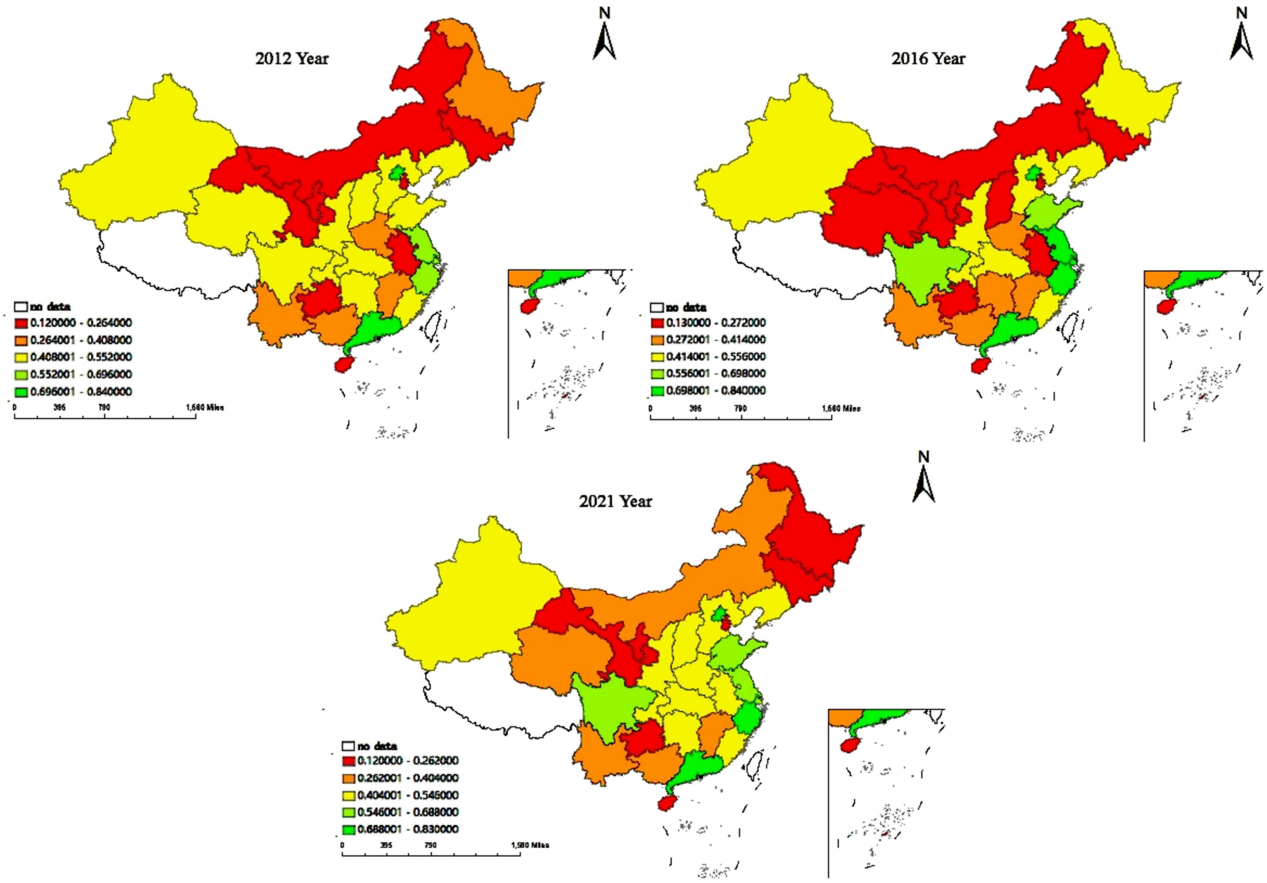

Figure 3 Spatial map of the distribution of coupling harmonization across regions in China.

Specifically, the eastern region (eg, Guangdong, Jiangsu, Zhejiang, Shandong) consistently maintained a leading position in coupling coordination in 2012, 2016, and 2021, with most provinces remaining in the "good coordination" or "primary coordination" range, exhibiting relatively minor fluctuations. In contrast, the central region (eg, Anhui, Jiangxi, Hubei) demonstrated a gradual upward trend, with multiple provinces transitioning from "transitional coordination" to "primary coordination".

Nevertheless, the western region (eg, Xinjiang, Qinghai) continued to lag behind, with most areas remaining in the "imbalance" or "transitional coordination" stage. Notably, Xinjiang and Qinghai persistently remained in a state of "imbalance" at all three observed time points—2012, 2016, and 2021.

Analysis of Factors Influencing the Degree of Coupled Coordination between the Digital Economy and Public Health Services

This study employs regression analysis to investigate the impact of government support, economic development level, population density, technological innovation capacity, human capital, and residents' health status on the coupling coordination degree between the digital economy and public health services. Furthermore, it examines the regional disparities in these effects (Table 5).

Government Support

The regression results indicate that government support (Gov) has a significant positive effect on the coupling coordination degree between the digital economy and public health services ($\beta = 0.152$, $p < 0.01$). However, the magnitude of this effect varies across regions. Specifically, government support plays a significant role in the western

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Table 5 Results of the Tobit Regression

Variable	Nationwide	Eastern Region	Central Region	Western Region
GOV	0.152***	0.037*	0.017**	0.083***
	(0.119)	(0.016)	(0.009)	(0.054)
LED	0.612***	1.318***	0.532**	0.417***
	(0.278)	(0.129)	(0.193)	(0.103)
POP	0.133**	−0.129**	0.082***	−0.052**
	(0.106)	(0.080)	(0.096)	(0.06)
TI	0.021	0.019*	0.097	0.043
	(0.043)	(0.009)	(0.041)	(0.032)
HC	0.181**	0.081**	0.076**	0.106**
	(0.076)	(0.196)	(0.147)	(0.096)
MR	−0.103***	0.004**	0.017**	−0.905***
	(0.031)	(0.010)	(0.038)	(0.356)
CONS	−0.895***	−0.681***	−0.935***	−0.461***
	(0.315)	(0.233)	(0.564)	(0.354)
N	300	110	80	110
R^2	0.943	0.961	0.957	0.932

Notes: *, **, *** denote 10%, 5% and 1%, respectively, by the significance level test, and the numbers in parentheses are standard deviations.
Abbreviaitons: Gov, government support; Led, economic development level; Pop, population density; TI, technological innovation capability; HC, human capital; MR, resident health level.

($\beta = 0.083$, $p < 0.01$) and central ($\beta = 0.017$, $p < 0.05$) regions. In contrast, while the effect remains positive in the eastern region, it is relatively weaker ($\beta = 0.037$, $p < 0.1$).

Economic Development Level

The regression results demonstrate that the level of economic development (Led) has a significant positive impact on the coupling coordination degree between the digital economy and public health services at the national level ($\beta = 0.612$, $p < 0.01$). Regionally, this effect is most pronounced in the eastern region ($\beta = 1.318$, $p < 0.01$), while it remains positive but relatively weaker in the central ($\beta = 0.532$, $p < 0.05$) and western ($\beta = 0.417$, $p < 0.01$) regions.

Population Density

The regression results reveal that population density (Pop) has a significant positive impact on the coupling coordination degree between the digital economy and public health services at the national level ($\beta = 0.133$, $p < 0.05$). However, regional analysis indicates notable variations in this effect. In the central region, population density exerts a positive influence on the coupling coordination degree ($\beta = 0.082$, $p < 0.01$). In contrast, it has a negative effect in both the eastern ($\beta = -0.129$, $p < 0.05$) and western ($\beta = -0.052$, $p < 0.05$) regions. These findings suggest that population density may influence the coupling coordination degree through different mechanisms across regions, highlighting the need for further investigation into its specific pathways of influence.

Technological Innovation Capacity

The regression results indicate that technological innovation capacity (TI) does not have a statistically significant impact on the coupling coordination degree between the digital economy and public health services at the national level ($\beta = 0.021$, $p > 0.1$). In the regional analysis, only the eastern region exhibits a weak positive effect of technological innovation capacity on the coupling coordination degree ($\beta = 0.019$, $p < 0.1$), while the effects in the central ($\beta = 0.097$, $p > 0.1$) and western ($\beta = 0.043$, $p > 0.1$) regions are not statistically significant.

Human Capital

The results show that human capital (HC) has a significant positive impact on the coupling coordination degree ($\beta = 0.181$, $p < 0.05$). Regionally, this variable exhibits a positive effect in the western ($\beta = 0.106$, $p < 0.05$), central ($\beta =$

0.076, $p < 0.05$), and eastern ($\beta = 0.081$, $p < 0.05$) regions, indicating that improvements in human capital contribute to enhancing the coupling coordination degree across different regions.

Resident Health Level

The regression results indicate that resident health level (MR) has a significant negative impact on the coupling coordination degree between the digital economy and public health services at the national level ($\beta = -0.103$, $p < 0.01$), suggesting that disparities in health status hinder coordinated development. Regionally, the negative effect is most pronounced in the western region ($\beta = -0.905$, $p < 0.01$), implying that relatively lower health levels in this area may impede the effective integration of public health services and the digital economy. Conversely, in the eastern ($\beta = 0.004$, $p < 0.05$) and central ($\beta = 0.017$, $p < 0.05$) regions, resident health level has a positive impact on the coupling coordination degree, indicating that higher health levels in these regions facilitate the coordinated development of the digital economy and public health services.

At the national level, government support, economic development level, and human capital exert significant positive effects on the coupling coordination degree between the digital economy and public health services. In contrast, resident health levels may have a suppressive effect in certain regions. The high R^2 values of the regression model ($R^2 = 0.943$ at the national level, $R^2 = 0.961$ in the eastern region, $R^2 = 0.957$ in the central region, and $R^2 = 0.932$ in the western region) indicate strong explanatory power for the coupling coordination degree. These findings suggest that the selected variables effectively account for regional disparities in coupling coordination.

Robustness Test

In order to ensure the correctness and validity of the conclusions obtained, the results obtained from the empirical analyses are tested for robustness. Therefore, we chose to regress the explanatory variables by replacing the original variables after shrinking and applying the year city double fixed effect model to regress the results obtained are consistent with Table 5. Therefore, the results of the study can be considered to pass the robustness test.

Conclusions and Policy Implications

Conclusion

This study, based on data from 30 provinces (including municipalities and autonomous regions) in China, employs a coupling coordination degree model to assess the level of integration and coordination between the digital economy and public health services. Additionally, a Tobit model is utilized to analyze the key influencing factors. The primary conclusions of this study are as follows:

Overall Coupling and Coordination Level Still Has Significant Room for Improvement

At the national level, from 2012 to 2021, the coupling coordination degree between the digital economy and public health services exhibited a slight upward trend. However, it remains within the range of "near-disordered" to "barely coordinated" states. This finding suggests that, despite the deepening integration of digital technologies into the healthcare sector—marked by notable advancements in telemedicine, intelligent health management, and big data analytics in healthcare[32]—the overall level of coordinated development between the digital economy and public health services remains relatively low. The digital economy has yet to fully drive the optimization and upgrading of the public health system.[33] Existing research further indicates that the impact of digital economic development on the public health system continues to be constrained by factors such as infrastructure deficiencies, policy support limitations, and resource allocation inefficiencies.[34]

A more detailed analysis of regional differences reveals that the coupling coordination degree in the eastern region is relatively higher, consistently maintaining a "barely coordinated" status. In contrast, the central and western regions not only exhibit lower levels of coordination than the national average but have also remained in a persistently disordered state, highlighting the imbalance in the collaborative development of the digital economy and public health services across regions. The key factors contributing to these disparities can be summarized as follows:

First, disparities in digital infrastructure development serve as a major influencing factor. The eastern region, benefiting from a strong foundation in digital economy development, has been an early adopter of advanced technologies such as 5G, the Internet of Things (IoT), and big data, resulting in a higher level of digitalization.[35] In contrast, the

central and western regions continue to face substantial gaps in digital infrastructure, constraining the application and widespread adoption of digital technologies in public health services. Research has demonstrated that the completeness of digital infrastructure directly influences the accessibility and efficiency of digital healthcare services.[36]

Second, the uneven distribution of public health resources exacerbates regional disparities. The eastern region is characterized by a higher concentration of high-quality medical resources and a generally better health status among residents, which facilitates the effective utilization of digital technologies to enhance public health services. Conversely, the central and western regions suffer from a relative shortage of public health resources, and grassroots medical institutions often exhibit lower levels of digitalization, restricting the potential of digital technologies to empower the public health system. Previous studies have indicated that the unequal distribution of medical resources contributes to the regional digital health divide and impedes the modernization of public health.[37]

Finally, variations in government policy support also influence regional differences in coupling and coordination levels. In the eastern region, governments have implemented relatively comprehensive policy measures to promote the integration of the digital economy with public health, such as supporting the development of "Internet+Healthcare", advancing telemedicine, and expanding digital health services. In contrast, fiscal constraints, limited policy guidance, and disparities in local economic development have hindered the central and western regions from formulating and implementing adequate support policies, thereby restricting the capacity of digital technologies to enhance public health systems.

Therefore, to bridge the regional gap in coupling and coordination, further efforts should focus on strengthening digital infrastructure in the central and western regions, optimizing the allocation of public health resources, and enhancing government policy support. These measures will be critical to fostering the collaborative and high-quality development of the digital economy and public health services.

Significant Divergence at the Urban Level, with Breakthroughs in Certain Regions

At the urban level, from 2012 to 2021, the coupling coordination degree between the digital economy and public health services across Chinese provinces and municipalities exhibited a distinct pattern of regional divergence. While certain cities, such as Beijing, Shanghai, and Jiangsu, have progressed to the "primary coordination" or even "good coordination" stage, the majority remain at the "transitional reconciliation" level or lower. Furthermore, between 2019 and 2021, the coupling coordination degree in some cities experienced a decline, exacerbating regional disparities.

Several key factors have driven advancements in specific cities. First, policy incentives have played a pivotal role in facilitating the integration of the digital economy with public health services. For instance, the Yangtze River Delta region has benefited from regional integration policies, resulting in increased government investment in initiatives such as health big data centers and smart hospitals, thereby enhancing the level of coupling coordination.[38] Second, the synergistic effects of industrial clusters have significantly contributed to the deep application of digital technologies in the public health sector. Provinces and municipalities such as Guangdong and Jiangsu have well-established digital healthcare enterprise clusters, which have further accelerated the digital transformation of public health services.[39,40]

Moreover, financial investment and infrastructure development are critical determinants of the coupling coordination level. Economically developed regions allocate substantial fiscal resources to accelerate the informatization of public health systems, thereby strengthening the role of digital technologies in supporting tiered medical services and public health monitoring. However, the overall performance of western regions remains relatively lagging. Notably, in 2021, only Sichuan Province reached the "primary coordination" level, whereas other western provinces remained in a state of "disequilibrium". This indicates that these regions continue to grapple with challenges such as an underdeveloped digital economy, uneven distribution of public health resources, and inadequate infrastructure development. Addressing these issues necessitates stronger government-led policy interventions and increased resource allocation to foster regional coordination and balanced development.

Overall, while the eastern region demonstrates relatively high coupling coordination, inefficiencies in resource allocation persist in certain provinces. The central region, on average, falls below the national coupling coordination level, while most western provinces (excluding Sichuan) remain in a state of disequilibrium. These findings underscore the significant influence of regional economic development levels, government support, and infrastructure investment on

the coupling coordination between the digital economy and public health services. Therefore, to mitigate regional disparities, it is imperative to further strengthen digital infrastructure in western provinces, optimize the allocation of public health resources, and enhance the specificity and effectiveness of government policies. These measures will facilitate the synergistic and high-quality development of the digital economy and public health services.

Differential Impact of Regional Economic Development and Government Support on Coupling Coordination

This study finds that the influence of economic development and government support on the coupling coordination degree between the digital economy and public health services varies significantly across regions. Economically developed regions exhibit stronger resource integration capabilities, with per capita GDP exerting a significant positive effect in both the eastern and central regions, as indicated by regression coefficients of 0.174 and 0.142, respectively. This suggests that these regions are well-positioned to leverage digital technologies to optimize their public health service systems. However, in the western region, economic development does not have a statistically significant impact on coupling coordination. This may be attributed to weak infrastructure, insufficient accumulation of digital resources, and limited public health service capacity, all of which hinder the translation of economic growth into tangible improvements in public health services.[41] Therefore, in addition to fostering economic growth, western regions must prioritize digital infrastructure development to enhance the synergy between the digital economy and public health systems.

Furthermore, government support plays a crucial role in improving coupling coordination in the central and western regions, with regression coefficients of 0.017 and 0.083, respectively. This underscores the pivotal role of government fiscal investment in mitigating resource shortages and supporting both public health service provision and digital economic development in these areas. By contrast, in the eastern region, the marginal effect of government fiscal support is relatively diminished, as coupling coordination depends more heavily on market-driven forces and technological innovation.

Given these regional disparities, policymakers should adopt differentiated fiscal investment strategies. In western regions, increased government investment is essential to compensate for market inefficiencies, while in the eastern region, optimizing the structure of fiscal support to enhance the synergy between market mechanisms and government resources will be key to further integrating the digital economy with public health services.[42]

The Critical Role of Human Capital and Technological Innovation in Coupling Coordination

The findings indicate that human capital has a significant positive effect on the coupling coordination degree at the national level, with a regression coefficient of 0.181. This suggests that higher education advancements play a critical role in facilitating the application of digital technologies in the public health sector.[43] In the eastern region, the abundance of higher education resources has fostered a well-developed talent cultivation system, which provides strong support for integrating the digital economy with public health services. However, due to the relative scarcity of higher education institutions and an inadequate talent pool, the central and western regions exhibit weaker capabilities in digital technology application, thereby hindering the coordinated development of these two systems. To bridge this regional disparity, policymakers should increase investment in higher education in the central and western regions, cultivating high-quality talent to enhance the application of digital technologies in public health services.

Furthermore, technological innovation capability has demonstrated a positive impact on coupling coordination in the eastern region (regression coefficient = 0.019, $p < 0.10$), underscoring its role as a crucial driver of digital economy–public health service integration.[44] The eastern region, benefiting from substantial research and development (R&D) investments, has successfully promoted the application of digital technologies in the healthcare sector, thereby improving the coordination between these two systems. However, in the central and western regions, technological innovation has not significantly contributed to coupling coordination, likely due to limited innovation resources and weaker technological application capabilities. To address this challenge, these regions should increase investments in digital and information technology research, strengthen industry-university-research collaboration, and promote the transformation and application of digital innovation achievements in the public health sector. Such efforts will enhance the synergistic development of the digital economy and public health services.

Policy Implications

Increasing Economic Investment in Western Regions to Promote the Integration of the Digital Economy and Public Health Services

Due to the weak economic foundation of the western regions, the coordinated development of the digital economy and public health services remains constrained. Therefore, it is recommended that the government increase fiscal investment, with a particular focus on supporting the construction of digital infrastructure and strengthening public health networks. Additionally, insights from the experiences of the eastern regions should be leveraged to optimize resource allocation and enhance the synergy between these two systems, thereby advancing the digital transformation of public health services.

Optimizing Government Fiscal Investment to Improve Fund Utilization Efficiency

In the central and western regions, ensuring stable growth in government financial support while enhancing transparency in fund allocation is crucial. This approach would enable fiscal investments to be precisely targeted toward the development of primary healthcare facilities and the optimization of digital infrastructure, ultimately improving the accessibility and equity of public health services. Meanwhile, in the eastern regions, fiscal expenditure structures should be refined to prevent resource misallocation. Financial resources should be concentrated on high-efficiency projects that integrate digital healthcare and public health services, thereby maximizing the effectiveness of public health investments in improving population health outcomes.

Strengthening Technological Innovation and Human Capital Investment

In the eastern regions, technological innovation serves as a cornerstone for fostering coordinated development. Therefore, sustained increases in research and development (R&D) investment should be promoted to propel advancements in digital healthcare technologies and strengthen the integration of artificial intelligence, big data, and related innovations into public health services. In contrast, the central and western regions should intensify their investments in technology R&D, particularly in digital healthcare and health information systems, to strengthen their innovation capacity and accelerate the deep integration of the digital economy with public health services. Regarding human capital, greater investment in educational resources is essential to expand the accessibility and quality of higher education. This will facilitate the cultivation of a larger pool of technology-driven innovators and highly skilled healthcare professionals, thereby reinforcing the long-term sustainability of the public health system.

Optimizing the Impact of Population Density on Coupling Coordination Development

In the eastern regions, excessive population concentration presents significant challenges. To mitigate this issue, efforts should focus on expanding the development of primary healthcare facilities, improving healthcare accessibility and efficiency, and alleviating the healthcare burden in major urban centers. These measures will contribute to a more equitable distribution of health resources across the population. Conversely, in the western regions, proactive strategies should be implemented to attract population inflows. This includes optimizing employment opportunities and improving living conditions to stimulate market vitality and enhance the capacity of public health services. Strengthening these aspects will improve the synergy between the digital economy and public health services, fostering more balanced regional development.

Research Limitations and Future Prospects

First, China has yet to establish a comprehensive and unified evaluation index system for assessing the coupling and coordinated development of the digital economy and public health services. Consequently, this study may have certain limitations in its selection of indicators and framework construction, potentially failing to fully capture the multi-dimensional characteristics of the coordination between these two systems. Second, due to constraints in the completeness and availability of public health service-related data, this study primarily relies on provincial-level data. While this approach provides valuable theoretical support at the macro level, it falls short in uncovering the underlying micro-level mechanisms. Additionally, the selection of influencing factors in this study focuses predominantly on fundamental and statistically significant variables, without incorporating broader and potentially complex determinants such as the sociocultural environment, policy interaction effects, and the depth of technological penetration. Future research should aim to develop a more rigorous and dynamic indicator system while leveraging cross-level and multidimensional data

mining techniques to gain deeper insights into the intricate driving mechanisms underlying the coupling and coordination between the digital economy and public health services. These efforts will contribute to a more comprehensive theoretical foundation and provide practical recommendations for enhancing the efficiency and synergy of both systems.

Disclosure

The authors report no conflicts of interest in this work.

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