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Measuring China's Digital Economy and Analyzing its Influencing Factors

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Abstract: In the information age, the digital economy will drive the transformation of the Chinese economy into high-quality development. In this paper, we define the digital economy in terms of input, output, and environment, measure China's digital economy by the entropy method and analyze its regional differences. Further, we analyze the spatial correlation between the provincial digital economies through the Moran index and then explore the factors that influence the development of the digital economy through the spatial Dubin model. We find that: First, China's digital economy is unbalanced in the provinces, with the level of development decreasing in three tiers based on the economic level of urban agglomerations. Specifically, the three economic centers of Beijing, Guangdong, and Shanghai are in the first tier, while the six provinces and cities of Jiangsu, Zhejiang, Shandong, Fujian, Sichuan, and Tianjin are in the second tier and the remaining provinces are in the third tier. Second, China's digital economy has spatial correlations across provinces, indicating that its development is not strictly constrained by regions. Third, further research shows that factors including economic development level, the intensity of government support, regional marketization, and industrial structure will propel the digital economy.

Keywords: digital economy; spatial Dubin model; new development pattern; regional marketization

JEL Classification: O11; C23; C52

1. Introduction

The sudden outbreak of COVID-19 has challenged traditional models of economic development. With its non-exclusive, non-contact, convenient, and innovation-driven characteristics, the digital economy has effectively reduced transaction costs and comprehensively reconstructed the social relations of economic activity. The total output of China's digital economy in 2020 surpassed 39.2 trillion yuan and accounted for 38.6 percent of the GDP (CAICT, 2020). To ensure the steady growth of the digital economy, the Fourteenth Five-Year Plan of China mentioned vigorously integrating the digital and the real economy, to speed up the establishment of a "dual circulation" development pattern.

Accurately defining the digital economy is the premise of this study. Sun and Wang (2004) believe a shift in production tools will inevitably change economic form. With the widespread use of modern production tools, the dominant industrial economy began to gradually shift to an information economy. Pang and Zhu (2013) also identify the digital economy as essentially using digital tools such as the Internet, mobile devices, and computers to digitize communication and consumer transactions. Meanwhile, the G20 Summit held in 2016 defined it as a broad economic activity with digital information as the key production element and modern information networks as vital carriers (G20 Digital Economy Task Force, 2016). However, the rapid digitization of the economy and society also created many governance difficulties, so digital economic connotation should cover digital governance. So, at the measurement level, we add the necessary dimension of the digital governance environment, characterized by government digital governance and enterprise digital governance.

The marginal contribution of this paper is that, first, we define the digital economy in terms of input, output, and environment to provide the theoretical basis for the construction of a measurement system. Second, we use the entropy method to measure China's current digital economy and further discuss the causes of the imbalance in provincial digital economies. Third, we select a spatial econometric model for empirical analysis to verify the factors affecting the development of China's digital economy and provide targeted policy recommendations.

2. The Connotation of the Digital Economy

The development pattern of the traditional economy has been transformed by the digital economy by innovating input factors, improving factor productivity, and optimizing the economic operating environment (Jing & Sun, 2019). Therefore, we define the connotation of the digital economy by exploring how it differs from the traditional economy in terms of inputs, outputs, and environment.

From an input perspective, data has become an essential factor of production in the digital economy (Yang, 2020). Unlike traditional elements such as land and capital, the production of data elements requires substantial investments in software and hardware and knowledge-intensive human capital at an early stage. Specifically, the explosive growth of data comes from the birth of networks such as the Internet and the Internet of Things, whose connectivity relies on various mobile and sensing terminals. Therefore, digital infrastructure investment is an indispensable "foundation" of the digital economy. Moreover, the process of transforming fragmented data into valuable data elements requires the involvement of sophisticated digital talent. As a result, the digital economy requires more highly skilled and innovative talents than the agricultural and industrial economies.

From an output perspective, changes in factor endowments spawned new industries and new formats, namely digital industrialization (Yang, 2020). Typically, the Internet-based software and information technology services industries emerged due to the rapid growth in demand for data analytics and software research and design. In addition, the deep integration of digital technologies with traditional industries is improving factor productivity, namely industrial digitalization (Wan et al., 2019). Specifically, agricultural digitalization applied IoT and intelligent detection technologies to improve production efficiency and expanded sales channels for agricultural products by building rural e-commerce. Industrial digitalization is reflected in the use of information technology by industrial enterprises to optimize their production processes. The digitalization of traditional service industries has improved the operational efficiency of the economy and society. For example, e-commerce solved the difficulty of finding and matching between trading parties, accelerating the flow of products.

Digital finance alleviates the borrowing difficulties of small companies and individuals (Laeven et al., 2015), thereby improving the productivity of the capital element as a whole.

From the environmental perspective, the utilization of digital technology improved the operational efficiency of governments and enterprises and thus optimized the economic operating environment. For the government, the integration of digital technology and public services, as represented by online government platforms, connects the government, enterprises, and people in a more efficient way. Meanwhile, digital construction such as "digital city" and government big data platforms will help the government to deeply understand the economic and social operation and achieve scientific and accurate social governance. For enterprises, the application of data mining techniques can help companies to identify potential demands that have been overlooked in the traditional economy, cultivate new market segments, and reduce supply distortions caused by information research and judgment errors, thus optimizing stock (Wu & Ren, 2022). In addition, big data technology can break down hierarchical barriers and accelerate information transmission within enterprises (Ren & Sun, 2022).

Table 1. Evaluation indicator system of the digital economy

Basic Dimensions	Secondary dimensions	Measurement indicators
Basic investment	Hardware facilities	Number of broadband access ports per square kilometer
		Number of broadband users per square kilometer
		Mileage of long-distance optical cable per square kilometer
		Number of mobile base stations per square kilometer
	Network resource	Number of IPv4 addresses
		Number of domain names
		Number of pages
	Intellectual input	Number of college students per 100,000 population
		The proportion of scientific research and technical service industry employees in total employment
		The proportion of information transmission, software and IT services employees in total employment
Digital industrialization	Telecommunication industry	The volume of telecommunication Services
		Mobile inter-access traffic
	Software and information technology industry	The scale of the software industry
		The scale of the IT service industry
	Electronic information manufacturing	Revenue of electronic information manufacturing industry
		Import and export volume of the electronic information manufacturing industry
Industrial digitalization	Agricultural digitalization	Length of rural delivery line per square kilometer
		Number of agrometeorological observation stations
	Industrial digitalization	Technical transformation cost of industrial enterprises
		The full-time equivalent of R&D staff in industrial enterprises
		Effective invention patents of industrial enterprises
	Electronic commerce	E-commerce sales
		The proportion of enterprises with e-commerce
	Digital finance	The digital inclusive financial index
Digital governance environment	Digital governance of government	Index of online government affairs capability
		Influence index of government microblog
	Digital governance of enterprise	Degree of digital transformation of listed companies

3. Methodology

3.1. Indicator System

From the above connotation, we establish an evaluation system from four basic dimensions: basic investment, digital industrialization, industrial digitization, and digital governance environment.

3.2. Entropy Method

Whether the weights of each dimension are scientifically reasonable determines the accuracy of the measurement. The entropy method is chosen to assign weights to each indicator, with the core idea that the smaller the entropy value of an indicator, the larger its dispersion and the larger its weight in the comprehensive evaluation; in turn, the weight is smaller. The formulas are as follows:

Step 1: Dimensionless processing of the original data. The original data is processed using maximum difference normalization so that the indicators can be compared horizontally. For the positive indicators, the transformation formula is as follows:

$$y_{ij} = \frac{x_{ij}-min\{x_j\}}{max\{x_j\}-min\{x_j\}} (i = 1,2,3 \dots, m; \ j = i, 2,3 \dots, n) \tag{1}$$

x_{ij} is the jth indicator in year i. $min\{x_j\}$ is the minimum in all years and $max\{x_j\}$ *is* the maximum.

Step 2: Computing the share of the *j*th indicator in all years.

$$p_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}} \tag{2}$$

Step 3: Computing the *j*th indicator's entropy e_j.

$$e_j = -\frac{1}{ln\, m}\sum_{i=1}^{m} p_{ij} \times ln\, p_{ij} \tag{3}$$

Step 4: Computing the information entropy redundancy d_j.

$$d_j = 1 - e_j \tag{4}$$

Step5: Computing the *j*th indicator's weight ω_j.

$$\omega_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{5}$$

Step 6: Calculate the Digital Economy Development Index (*DEDI*) for each province. The value of the *DEDI* ranges from 0 to 1 and is positively correlated with the level of digital economy development.

$$DEDI_i = \sum_{j=1}^{n} \omega_j \times y_{ij} \tag{6}$$

3.3. Spatial Dubin Model

To explore the factors affecting China's digital economy, we carry out an empirical test by the spatial Dubin model. The specific structure is as follows.

$$DEDI_{it} = \rho wDEDI_{it}+\beta X_{it} + \delta wX_{it}+\varepsilon_{it} \tag{7}$$

Where: $DEDI_{it}$ is the digital economy development index of the *i*th province in year *t*. X_{it} is the set of explanatory variables, containing economic development level ($Pgdp_{it}$), the intensity of government support (Gov_{it}), the degree of regional marketization (Mar_{it}), and industrial structure (Ind_{it}). ρ is the spatial auto-regressive coefficient, which measures the mutual influence of digital economy among neighboring provinces. w is the economic distance spatial weight matrix, δ measures the impact of the explanatory variables in neighboring provinces on the *DEDI* of this province, ε_{it} is the random error.

3.4. Data Resource

Taking into account data availability and scientific accuracy, the data from 30 provinces in China from 2015 to 2019 are selected, excluding Tibet, Hong Kong, Macao, and Taiwan. The original data are obtained from Statistical Yearbooks of provinces, the China Stock Market & Accounting Research Database, the Institute of Digital Finance Peking University, the Public Opinion Data Center of People's Daily Online, the E-government Research Center of National Academy of Administration, Marketization Index of China's Provinces Database. In addition, due to differences in the magnitudes of the original data in the empirical test section, these data are processed logarithmically.

4. Results

4.1. Analysis of the Digital Economy Development Gap among Provinces

Based on the entropy method and the evaluation index system, we calculate the digital economy development index (DEDI) of 30 Chinese provinces from 2015 to 2019, shown in Figure 1. Further analysis shows that the Chinese average digital economy index increased year-on-year. Specifically, in 2019, it increased by 67.32% compared to 2015. This indicates that the implementation of "Internet Plus", "Digital China" and other relevant digital strategies since 2015 has achieved remarkable results, and the digital economy has achieved great development on the whole.

However, at the spatial level, the development of China's digital economy is uneven, and 30 provinces can be ranked in three tiers according to their *DEDI*, as illustrated in Table 2. The first tier contains Beijing, Guangdong, and Shanghai, all sitting in the core economic area. The three regions focused on cutting-edge digital technologies and digital industries and promoted the digital transformation of favored industries to form a strong integrated strength. Driven by the first tier, Jiangsu, Zhejiang, and Fujian in the Pan-Yangtze River Delta, as well as Shandong and Tianjin in Bohai Rim New Area and Sichuan in southwest China, also have a comparatively developed digital economy, thereby belong to the second tier. This tier takes full advantage of its industrial base and geographical position and focuses on building its strengths. The remaining 21 provinces have a slight gap in the digital economy, with an average annual development index below 0.1, falling into the third tier. Although the overall level of development in this tier is relatively low, some regions have unique patterns of digital economy development that can serve as a reference for others.

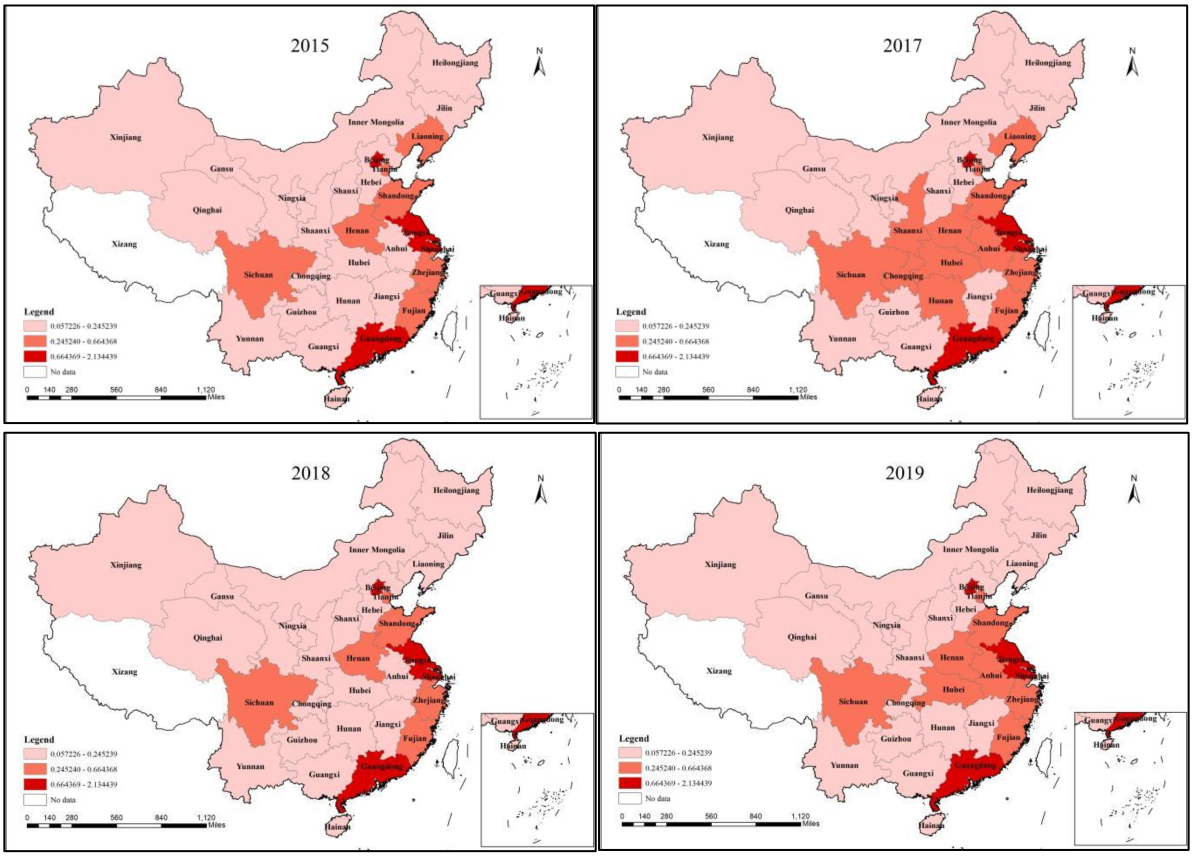

Figure 1. Spatial distribution of China's DEDI index for selected years

Table 2. Distribution tier of the digital economy in 30 Chinese provinces

The tier of the digital economy	Province and city
First Tier	Beijing, Guangdong, Shanghai
Second Tier	Jiangsu, Zhejiang, Shandong, Fujian, Sichuan, Tianjin
Third Tier	Henan, Hubei, Anhui, Liaoning, Shaanxi, Hunan, Chongqing, Hebei, Jiangxi, Guangxi, Shanxi, Hainan, Yunnan, Jilin, Guizhou, Heilongjiang, Gansu, Inner Mongolia, Xinjiang, Ningxia, Qinghai

Developing the digital economy has certain requirements on the self-development ability and industrial foundation of the region, which limits most of the less developed provinces and cities in China from developing their digital economy. We decompose the *DEDI* of each province according to the four basic dimensions to explore their strength of development.

Table 3 shows that the largest contribution dimension is a basic investment in 5 provinces, digital industrialization in 10 provinces, and industrial digitization in 15 provinces, while the digital governance environment is not the largest contribution dimension in any province. The possible explanation is that during the development process of the digital economy in recent years, most provinces and cities have focused on improving digital infrastructure,

Table 3. The largest contribution dimension of the digital economy in each province

The largest contribution dimension	Province	The index of the largest contribution dimension
Basic investment	Beijing	0.0301
	Shanghai	0.0177
	Tianjin	0.0057
	Hainan	0.0026
	Qinghai	0.0012
Digital industrialization	Guangdong	0.0368
	Jiangsu	0.0242
	Zhejiang	0.0108
	Shandong	0.0094
	Sichuan	0.0077
	Fujian	0.0060
	Henan	0.0048
	Shaanxi	0.0047
	Chongqing	0.0046
	Liaoning	0.0041
Industrial digitalization	Anhui	0.0052
	Hunan	0.0046
	Hubei	0.0044
	Hebei	0.0036
	Jiangxi	0.0027
	Guangxi	0.0026
	Shanxi	0.0024
	Yunnan	0.0024
	Guizhou	0.0022
	Jilin	0.0020
	Inner Mongolia	0.0020
	Heilongjiang	0.0018
	Gansu	0.0018
	Xinjiang	0.0017
	Ningxia	0.0013

building digital industries, and promoting the digital transformation of traditional industries. As a result, digital governance has not received sufficient attention and is still in the initial stages of building a government system that has yet to fully function. However, the digital governance environment will not only help improve the operational efficiency of the digital economy and optimize resource allocation but also help improve the convenience and happiness of people's lives. Since 2015, China has embarked on a major push to develop its digital economy. At present, the digital base in some provinces is relatively saturated and even partially redundant. Next, the establishment of a digital governance environment should be an important development direction.

For first- and second-tier provinces and cities, basic investment is the largest contribution dimension for Beijing and Shanghai, and digital industrialization is the largest for Guangdong, Jiangsu, Zhejiang, Shandong, Fujian, and Sichuan. These results show that the eight provinces with developed digital economies have focused on consolidating their digital foundations, and their rich digital manpower and large-scale digital industries have created strong and realistic competitiveness in their digital economies. For the third-tier provinces, Hainan and Qinghai have prioritized infrastructure construction despite their undeveloped digital economies, which will contribute to the introduction of emerging digital industries and the integration of traditional industries and digital technology in the future. However, for the 15 provinces with industrial digitalization as the largest contribution dimension, over-emphasis on the digital transformation of traditional industries while neglecting basic investment and digital industrial development may leave their future digital economy facing problems such as lack of digital manpower and lack of competitiveness of digital industries.

To further explore the causes of the development gap between the three tiers, we subdivide the digital economy index of each province according to 12 secondary dimensions to compare the development differences in each tier. The result of the subdivision is shown in Figure 2.

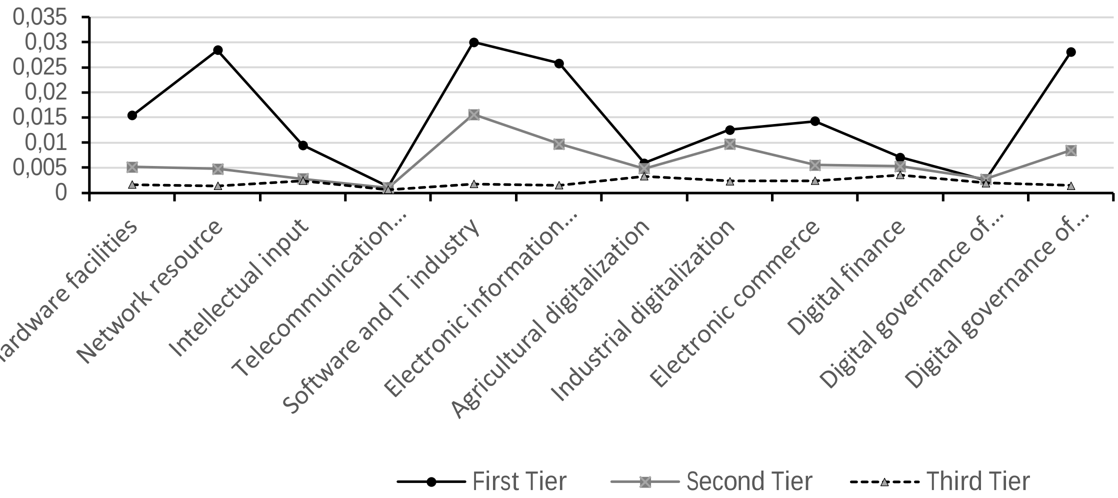

Figure 2. The digital economy development index for each tier based on secondary dimensions

The first tier is better developed than the second and third tiers in the following dimensions: hardware facilities, network resources, software and IT industry, electronic information manufacturing, and digital governance of the enterprise. The possible explanation is that Beijing, Guangdong, and Shanghai in the first tier are leading the country in terms of economic development level and richness of research resources, which provide solid financial support and technical support for the construction of their hardware and software infrastructure. In addition, their industrial development is oriented toward technological innovation, with a focus on cultivating or introducing highly innovative emerging digital industries. As a result, their digital industries have grown earlier and on a larger scale.

The gap between the second and third tiers exists in the dimensions of the software and IT industry, industrial digitalization, electronic information manufacturing, and digital governance of enterprises, while the remaining dimensions have relatively close development levels. The development of 12 dimensions within the second tier is also quite different, but the gap is not as sharp as in the first tier. Specifically, the development strengths of the second tier are the software and information technology industry, electronic information manufacturing, industrial digitalization, and digital governance of the enterprise. The development levels of the 12 dimensions within the third tier are relatively close, and all of them are at a low level, so there is a large room for development.

The above analysis shows that the development disadvantages of all three tiers are concentrated in the telecommunication industry, agricultural digitization, and digital governance of government. As a result, China's digital economy should focus more on these three shortcomings, vigorously develop digital agriculture and enhance the government's capacity for digital governance. In addition, differences in infrastructure investment have led to a serious "digital divide" between provinces. In economically developed provinces, advanced and well-developed digital infrastructure and abundant knowledge-intensive human resources enable the "network dividend" to be fully released, promoting the rapid expansion of digital industries. However, in economically undeveloped provinces, the lack of digital infrastructure has also prevented them from upgrading their industrial structure with new-generation information technology (Yan & Sun, 2012). In addition, the policies and regulations related to the digital economy in less developed provinces are relatively backward, hindering the construction of digital industrial bases and the introduction of digital enterprises (Yi et al., 2019).

4.2. Analysis of Provincial Spatial Correlation in China's Digital Economy

Spatial correlation is defined as the clustering of observed values of similar variables within a location. Wu (2006) believes that when the economic development of different regions is spatially dependent, location factors will affect the economic level, thus the estimator obtained by the ordinary least squares method is invalid. In this context, a spatial econometric model is needed to explore the factors influencing economic development. The Moran Index was chosen to test whether the provincial digital economy in China is spatially correlated. As is shown in Table 4, the significant positive value of the Moran Index indicates that the development of China’s digital economy is spatially correlated, and it also suggests that developing the digital economy itself is not strictly constrained by geographical location.

Table 4. Moran index of China's digital economy from 2015 to 2019

Year	Moran Index	Z-value	P-value
2015	0.319	3.302	0.001
2016	0.319	3.295	0.001
2017	0.318	3.278	0.001
2018	0.292	3.043	0.002
2019	0.286	2.984	0.003

4.3. Analysis of Factors Influencing China's Digital Economy

The fitting results of the SDM model are reported in Table 5, where the coefficients ρ and δ are significant, suggesting again that China’s digital economy is spatially correlated. Additionally, the variance inflation factor (VIF) can be used to check serious multicollinearity, with a VIF greater than 10 indicating severe multilinearity among explanatory variables. As shown in Table 5, the VIF of all explanatory variables is smaller than 10, so there is no serious multicollinearity. From the significant results of the explanatory variables, the economic development level, the degree of government support, the degree of regional marketization, and the industrial structure will effectively boost the digital economy.

Table 5. Regression results of an econometric model

Variables	SDM	OLS	VIF
Pgdp	0.9631*** (0.1350)	0.5644*** (0.0893)	3.50
Gov	0.2913*** (0. 0261)	0.3179*** (0. 0359)	3.37
Mar	0.8765*** (0. 1315)	0.9553*** (0.1666)	3.18
Ind	1.2077*** (0. 2873)	1.7202*** (0.3344)	1.66
ρ	-0.7479*** (0. 0882)		
δ	0. 0333*** (0. 0040)		
cons		-3.1331*** (0. 2809)	
N	150	150	

Note: * represents P-value <0.1, ** represents P-value<0.05, *** represents P-value<0.01; N is the sample size; numbers in parentheses are standard deviations.

The regional economic level will promote the digital economy from infrastructure, industrial base, innovation factors, and industrial introduction. First, economically developed regions tend to pursue high-quality economic development. While promoting rapid economic growth, they are also focusing on building digital infrastructures, like 4G base stations, fiber optic cables, and even 5G base stations, which are substructures for developing a digital economy. Second, the industrial layout in economically developed regions is relatively perfect, including basic digital industries such as electronic manufacturing and the IT industry, which has laid a solid hardware and software foundation for digital transformation (Liu et al., 2020). Finally, economically developed regions gather abundant educational and scientific research resources and thus are rich in talent, technology, and other elements of digital innovation, which is conducive to major technological breakthroughs and high-tech industry development.

The breakthroughs and transformations of major scientific and technological achievements will motivate the rapid growth of the digital economy. For example, breakthroughs in digital technologies like 5G and block-chains have made economic societies smarter. However, as a public good with a positive externality, basic research has a clear social spillover effect, which makes it difficult to achieve an efficient supply of basic research only through supply and demand adjustment by market mechanisms. Therefore, the intensity of government support in basic research will markedly affect the digital economy. The government should take the lead in connecting universities, research institutes, and enterprises, and provide the necessary financial support to jointly promote basic research in the new generation of digital technologies.

The degree of regional marketization is judged based on its product market, factor market, and legal environment in a comprehensive way (Wang et al., 2021). The higher the degree of marketization, the more mature the market mechanism and the perfect legal environment. On the one hand, in a highly market-oriented environment, the flow of input factors and the transmission of information is smoother. As a result, microeconomic entities such as businesses respond more quickly to fresh market information than they would in a less market-oriented environment. On the other hand, microeconomic entities, mostly dependent on government directives and policies for their development in a low-marketization environment, are on a path of investment-driven development (Wang & Huang, 2021). However, microeconomic entities in highly market-oriented environments face a higher competitive environment and their development is more driven by innovation.

The development experience of developed countries shows that during the transition to industrialization, the industrial structure will gradually shift from labor-intensive to capital-intensive and finally to technology-intensive (Tang & Feng, 2019). According to the National Economic Industry Classification Standard, the modern service sector, represented by IT services, belongs to the technology-intensive sector. Thus, the deepening industrialization will upgrade China’s industrial structure and ultimately boost its digital economy. Additionally, optimizing the industrial structure means that the proportion of tertiary sectors in the three sectors will increase. Modern services and modern commerce below the tertiary sector, represented by e-commerce, have a distinctly digital character. Therefore, upgrading the industrial structure of the region will boost the digital economy by expanding these modern digital industries.

5. Conclusions

Here are the main conclusions of the study: First, China's digital economy is spatially uneven, with 30 provinces showing a three-tier decline in the digital economic level. Specifically, the first tier performed significantly better than the second and third tiers in terms of the development of hardware facilities, network resources, software and IT industry, electronic information manufacturing, and digital governance of the enterprise. The development shortcomings of the three tiers are concentrated in the dimensions of the telecommunication industry, agricultural digitization, and digital governance of government. Second, China’s digital economy has significant spatial correlations, so its development is not strictly limited by geographical location. Third, the level of regional economic development, government support, regional marketization, and industrial structure will positively affect the development of the digital economy.

As a result, we propose that China could implement a differential digital economy strategy for different tiers and industries. The first tier could actively establish a system of industrial-university research cooperation to promote basic research and focus on high-end and cutting-edge fields. The second tier could pay attention to the development linkages with the first tier, and actively integrate into the regional development strategic action. The third tier, as a whole, could focus on strengthening its digital infrastructure. Meanwhile, Chongqing, Hubei, and Anhui provinces could choose a targeted digital strategy based on their strong manufacturing bases. With rich natural and cultural resources, Tibet and Xinjiang could actively implement digital culture innovation and digital tourism.

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