Original Research Article

The Measurement and Spatial-Temporal Distribution of the Development Level of China's Digital Economy

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ABSTRACT

Aims: Based on the latest classification standard of digital economy issued by the National Bureau of Statistics of China, this paper makes statistical measurement and analysis of the spatial and temporal distribution of the development level of China's digital economy.
Study design: Establish an indicator system for the development level of the digital economy and measure the spatial correlation between different regions.
Place and Duration of Study: School of Statistics and Application, Anhui University of Finance and Economics, China March to May 2023.
Methodology: Entropy method, kernel density estimation, Moran's I index and other statistical methods.
Results: It is found that China's digital economy is developing rapidly, but the development is obviously unbalanced, and the gap between high and low levels is increasing year by year. The development level of digital economy in provinces and cities has positive spatial autocorrelation, showing low-low clustering and high-high clustering spatial agglomeration phenomenon.
Conclusion: It is suggested to increase investment in digital innovation, strengthen regional cooperation, and adopt policies based on local conditions, so as to narrow regional gaps and promote the healthy and sustainable development of digital economy.

Keywords: Entropy method; Spatial and temporal distribution; Kernel density estimation; Moran's I index

1. INTRODUCTION

In recent years, modern information technology has developed rapidly, and the world has entered the era of digital economy dominated by big data, cloud computing and other digital science and technologies. Digital economy has also become one of the main driving forces of China's economic growth. According to the White Paper on theDevelopment of China's Digital Economy (2022), the scale of the digital economy will reach 45.5 trillion yuan in 2021, with a nominal year-on-year growth of 16.2 percent[1]. However, with the rapid development of digital economy, some problems are also accompanied by them. For example, there is no unified definition of digital economy, the lack of sufficient coverage and unified evaluation indicators, and the unbalanced and inadequate development of digital economy in various regions. Therefore, it is urgent to build a complete and unified digital economy index system to measure regional heterogeneity, so that provinces and cities can understand their own development level of digital economy development and their advantages and disadvantages in the process of development, so as to narrow regional differences and promote high-quality development in the new era.

At present, scholars' research on digital economy mainly focuses on connotation definition and index construction and measurement. In terms of concept definition, although the digital economy is defined by both academia and officials, a unified concept has not been formed so far. Don Tapscott The first to put forward the concept of digital economy and described its characteristics[3]. Mesenbourg That it includes three parts: telecommunications services, e-commerce, and digital infrastructure[4]. Although China's digital economy started late, it has developed rapidly. Its connotation was uniformly defined for the first time in the G20 Summit held in 2016, which is an economic activity that uses digital knowledge and information as key factors of production[5]. In 2021, the National Bureau of Statistics issued the Statistical Classification of Digital Economy and Its Core Industries (2021), which defined the concept of digital economy and core industries for the first time, providing a unified and comparable caliber for the accounting of China's digital economy indicators[6]。

In terms of the construction and measurement of digital economy indicators, most scholars select representative indicators to measure the level of development of digital economy. Margherio et al. originally in 1999 determined the accounting scope of the digital economy, including e-commerce, digital delivery of goods and services, network construction and retail of tangible goods[8]. Mesenbourg Only focus on e-commerce and its transactions[9]. Liu Jun et al. build an index system from three aspects of digital trading, Internet development and information development, and measured the digital economy through the empowerment of NBI index[11]. Kuang Jinsong et al. used the entropy Topsis method to measure the digital economy development level of China and provinces and cities in China from 2015 to 2017, and used visual maps to show the spatial evolution pattern[12]. Liu Chengkun et al. used the entropy Topsis method to build a new growth momentum index system, and analyzed the development degree of digital economy in various provinces and cities with the help of E SDA and nuclear density estimation[13]。

Through combing and summarizing relevant literature at home and abroad, it can be found that scholars have rich research on the definition and measurement of digital economy. Most of them use entropy method to build index system. However, there is still a complete and unified classification standard and index evaluation system has not been formed, and there are few studies on development heterogeneity in various regions. Based on the newly released "Statistical Classification of Digital Economy and Its Core Industries (2021)", and referring to the domestic and foreign digital economy measurement index system, this paper selects 21 indicators from the two aspects of "digital industrialization" and "industrial digitalization", and constructs the index system with the help of entropy value method. The nuclear density estimation and Moran's I index were used to measure the development and spatial distribution characteristics of digital economy in 30 provinces and cities from 2011 to 2020, and then explore the development characteristics of China's digital economy, so as to put forward policy suggestions for high-quality and coordinated development of digital economy in various regions.

2. CONSTRUCTION AND MEASUREMENT OF DIGITAL ECONOMY DEVELOPMENT LEVEL INDEX

2.1 Establish An Index System Of The Development Level Of The Digital Economy

2.1.1 Index selection

The Statistical Classification of Digital Economy and Its Core Industries corresponds to the classification of national economy, and the digital economy industry is divided into five categories: digital product manufacturing industry, digital product service industry, digital technology application industry, digital factor driving industry, and digital efficiency improvement industry. Among them, the first four categories correspond to the 26 major categories of the national economy industries, which are the core industries of the digital economy. The last category corresponds to the 91 major categories of the national economy industries. In view of this, this paper also reference the relevant index system, follow the data of scientific, quantifiable, available, as well as objectivity, the digital economy five child industry construction for secondary indicators, according to the specific content of each child industry built 21 level 3 indicators, composed of their digital economy development level index system, as shown in table 1.

Table 1.Index system of digital economy development level

SECONDARY INDEX	TERTIARY INDEX	ATT RIB	WEIGHT (%)
DIGITALPRODUCT MANUFACTURING INDUSTRY (26.80%)	Operating income of computer, communications and other electronic equipment manufacturing industry(100 million yuan)	+	6.24
	Total assets of computer, communications and other electronic equipment manufacturing industry (100 million yuan)	+	5.93
	Number of legal person units of computer, communications and other electronic equipment manufacturing enterprises (one)	+	7.95
	Average number of workers in the computer, communications and other electronic equipment manufacturing industry (person)	+	6.67
DIGITAL PRODUCT SERVICES INDUSTRY (29.39%)	Sales of communication equipment above quota (ten thousand yuan)	+	9.04
	Retail sales of communication equipment above the quota (ten thousand yuan)	+	5.24
	Sales of electronic publications and audio and video products above quota (ten thousand yuan)	+	8.22
	Sales of electronic publications and audio and video products above quota (ten thousand yuan)	+	4.11
	Number of legal person units of computer and office equipment maintenance enterprises (one)	+	2.79
DIGITAL TECHNOLOGY APPLICATIONS INDUSTRY (13.75%)	Main business revenue of telecom (RMB 100 million yuan)	+	1.69
	Software business revenue (RMB ten thousand yuan)	+	5.52
	Number of units in information transmission, software and information technology service enterprises (units)	+	3.51
	Number of employees in information transmission, software and information technology services (ten thousand)	+	3.04
DIGITAL ELEMENTS DRIVE THE INDUSTRY (27.04%)	E-commerce sales volume (RMB 100 million yuan)	+	4.29
	Number of Internet IPV 4 addresses (ten thousand)	+	4.05
	Number of Internet broadband access ports (ten million)	+	1.87
	Number of radio and television employees (person)	+	1.39
	Number of electronic publications published (ten thousand copies)	+	7.43
	Number of audio recordings and video products published(Ten thousand boxes / ten)	+	8.01
DIGITAL EFFICIENCY IMPROVEMENT INDUSTRY	Total power of agricultural machinery (ten thousand kilowatts)	+	2.07
	Enterprises with e-commerce transaction activities account for (%)	+	0.95

2.1.2Data sources

This data from the China statistical yearbook, China basic unit statistical yearbook, China industrial statistical yearbook, China economic census yearbook, China high technology industry statistical yearbook, China's trade statistical yearbook and the third industry statistical yearbook, as well as the net, the research network database, and eliminate the data does serious provinces. Finally, panel data of 21 indicators from 30 major provinces and cities (except Xizang, Hong Kong, Macao and Taiwan) from 2011 to 2020 were selected.

2.1.3Data processing method

In the data collection, it was found that some data were missing or statistical standards were different among provinces, which could not be compared, and relevant indicators could only be replaced. Finally, 21 indicators with representative features, all provinces and consistent statistical caliber were determined. Among these 21 indicators, the following two methods: interpolation method and recursive method. If an indicator only lacks the data of a certain year, and the data is continuous before and after, interpolate and fill; if an indicator lacks the data for several years, use recursive or linear trend method to complete the known data according to the specific situation.

2.2Digital Economy Development Index Measurement

2.1.1Measurement method

After selecting the indicators, it is necessary to assign power to each index to calculate the digital economy development index. Empowerment methods are subjective and objective, which rely on subjective judgment, the most common method is principal component analysis; objective method is based on the original data of each index, and common methods include entropy method and cluster analysis. Since the results of subjective empowerment do not depend on human subjectivity and are widely used, the entropy method is used to calculate the weights.

The entropy method is empowered by calculating the observed worthy information entropy of each index. Entropy is a measure of uncertainty information, the larger the information entropy, the smaller the utility value representing the information, the smaller the weight. Conversely, the smaller the information entropy, the greater the weight. In short, the entropy method is an empowerment method that considers the relative influence of the index relative changes on the whole system. The basic steps are as follows:

Dimensionless processing of data. Considering the different units of different indicators, it is necessary to standardize all indicators before calculating comprehensive indicators, so as to make the heterogeneity of all indicators become consistent, so as to have horizontal comparability,the principle is to convert each absolute index to a relative value. i represents the province, t represents the time, j represents the indicator, the dimensionless value is:

Positive Indexes: $$y_{ijt}=\frac{x_{ijt}-\min\{x_{jt}\}}{\max\{x_{jt}\}-\min\{x_{jt}\}}$$

Negative indexes: $$y_{ijt}=\frac{\max\{x_{jt}\}-x_{ijt}}{\max\{x_{jt}\}-\min\{x_{jt}\}}$$

Information entropy and redundancy were calculated. Province i, in year t, the weight of index j, we call it P_{ijt}, information entropy is e_j, redundancy rate is d_j.

$$P_{ijt} = \frac{y_{ijt}}{\sum_{i=1}^{n}\sum_{j=1}^{m} y_{ijt}}$$

$$e_j = -\frac{1}{\ln m \times T}\sum_{i=1}^{n}\sum_{j=1}^{m}(p_{ijt} \times \ln p_{ijt})$$

$$d_j = 1 - e_j$$

Considering the different units of different indicators, it is necessary to standardize all indicators before calculating comprehensive indicators, so as to make the heterogeneity of all indicators become consistent, so as to have horizontal comparability, the principle is to convert each absolute index to a relative value.

Determine the weight of the index. The weight of the evaluation index is calculated according to the redundancy, the formula is as follows:

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j}$$

Comprehensive evaluation index. Based on the standardized index y_{ijt} and the weight of each index w_j, Weighted to sum up to finally determine the digital economy development index F.

$$F_{it} = \sum_{j=1}^{m} w_j y_{ijt}$$

F_{it} represents the digital economy development index of province i in year t, it ranges from 0 to 1, the higher the value, the higher the development level of digital economy.

2.2.2Calculation results and analysis

The average contribution weight of each index of the digital economy development index is shown in Table 1. The contribution weight of the five second-level indicators is 26.80%, 29.39%, 13.75%, 27.04% and 3.02%, respectively. The average contribution weight of the above 21 three-level indicators is multiplied by the standardized original data to obtain the comprehensive score of each index. After addition, the digital economy development index of a certain province in a certain year, as shown in Table 2.

Overall, China's digital economy has developed rapidly in the past decade. The average development index of the digital economy has increased from 0.0574 to 0.1138, with an average annual growth rate of 7.90%. At the same time, it is not difficult to see that the development level of digital economy in all provinces has been greatly improved. The development level of Guangdong, Beijing, Jiangsu and other cities is at the forefront, while Guizhou and Chongqing have a fast growth rate and a strong development momentum. However, there is still a large gap in digital economy development between provinces. For example, the 2020 digital economy development index of Guangdong (0.608) is 76.4 times that of Qinghai (0.008).

Table 2. Results of digital economy development index measurement

	PROVINCE	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Eastern Region	Beijing	0.182	0.190	0.190	0.249	0.234	0.243	0.301	0.357	0.436	0.461
	Tianjin	0.021	0.027	0.045	0.034	0.037	0.037	0.037	0.040	0.041	0.044
	Hebei	0.045	0.051	0.049	0.060	0.061	0.063	0.069	0.072	0.077	0.080
	Liaoning	0.128	0.098	0.130	0.105	0.062	0.057	0.062	0.062	0.060	0.062
	Shanghai	0.138	0.153	0.163	0.185	0.205	0.216	0.213	0.212	0.206	0.204
	Jiangsu	0.198	0.246	0.273	0.287	0.303	0.326	0.344	0.333	0.354	0.366
	Zhejiang	0.087	0.102	0.111	0.126	0.126	0.153	0.176	0.190	0.205	0.218
	Fujian	0.044	0.047	0.054	0.055	0.062	0.071	0.082	0.085	0.090	0.093
	Shandong	0.088	0.101	0.102	0.122	0.130	0.139	0.155	0.164	0.172	0.173
	Guangdong	0.296	0.324	0.360	0.394	0.399	0.469	0.535	0.566	0.605	0.608
	Hainan	0.007	0.007	0.006	0.009	0.012	0.014	0.013	0.015	0.016	0.015
Middle Region	Shanxi	0.018	0.023	0.024	0.027	0.030	0.031	0.032	0.036	0.038	0.044
	Nei Monggo	0.015	0.017	0.017	0.018	0.020	0.023	0.025	0.026	0.028	0.029
	Jilin	0.017	0.019	0.019	0.022	0.024	0.026	0.028	0.029	0.029	0.028
	Heilongjiang	0.018	0.020	0.048	0.058	0.034	0.028	0.032	0.039	0.033	0.034
	Anhui	0.032	0.037	0.040	0.050	0.056	0.061	0.069	0.078	0.082	0.092
	Jiangxi	0.028	0.034	0.035	0.039	0.046	0.051	0.059	0.063	0.074	0.083
	Henan	0.061	0.074	0.067	0.072	0.092	0.093	0.104	0.112	0.106	0.109
	Hubei	0.044	0.051	0.049	0.066	0.069	0.073	0.089	0.091	0.097	0.105
	Hunan	0.058	0.063	0.064	0.065	0.073	0.073	0.076	0.086	0.089	0.093
	Guangxi	0.040	0.045	0.023	0.026	0.030	0.034	0.036	0.040	0.045	0.049
Western Regions	Chongqing	0.026	0.031	0.037	0.046	0.057	0.064	0.068	0.077	0.083	0.081
	Sichuan	0.051	0.061	0.065	0.073	0.073	0.083	0.094	0.107	0.121	0.128
	Guizhou	0.010	0.011	0.013	0.016	0.020	0.024	0.027	0.030	0.031	0.033
	Yunnan	0.020	0.029	0.025	0.027	0.031	0.038	0.036	0.036	0.040	0.041
	Shaanxi	0.022	0.032	0.029	0.037	0.043	0.052	0.056	0.061	0.067	0.066
	Gansu	0.012	0.012	0.011	0.013	0.016	0.017	0.016	0.018	0.019	0.020
	Qinghai	0.002	0.003	0.002	0.003	0.006	0.008	0.007	0.007	0.007	0.008
	Ningxia	0.004	0.007	0.004	0.006	0.008	0.008	0.008	0.008	0.008	0.009
	Xinjiang	0.011	0.011	0.012	0.016	0.018	0.019	0.029	0.031	0.042	0.037

3. SPATIAL AND TEMPORAL CHARACTERISTICS OF DIGITAL ECONOMY DEVELOPMENT LEVEL

3.1 Analysis Of The Time Change Trend Of The Digital Economy Development Level

In order to further understand the overall distribution and change trend of the development level of digital economy in various regions over time in China, the nuclear density is estimated based on the calculated digital economy development index of 30 major provinces and cities from 2011 to 2020, and the corresponding nuclear density estimation mountain peak map is drawn.

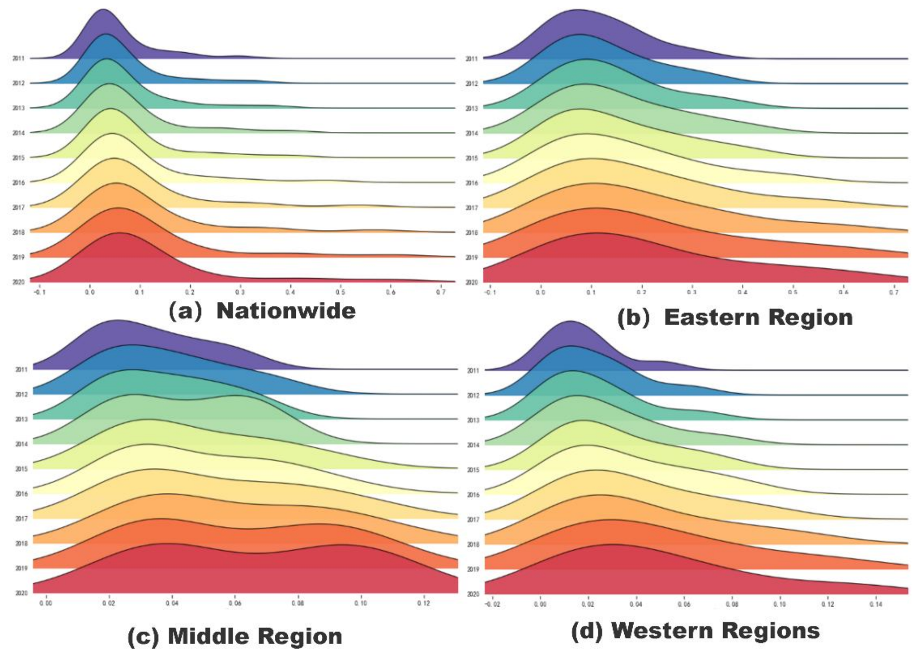

Figure 1. Kernel density estimation

First for the distribution of the overall digital economy development index, as shown in figure 1 (a), the overall curve is relatively steep unimodal form, the peak curve distribution at a lower level, it can be seen that compared with individual digital economy development level of provinces and cities, most of the other provinces and cities are still in a relatively low level of development. At the same time, the overall peak width of the curve is large, and there is a serious tail-dragging phenomenon on the right side of the curve, and it is gradually expanding with the passage of time, indicating that the gap between high and low levels is still increasing year by year.

Secondly, according to the distribution of the eastern, central and western regions, as shown in Figure 1 (b), the peak of the eastern region is basically at the same level, except that the area on the side of the right side of the curve increases year by year, the change trend of the curve is not quite different. This shows that the development of the digital economy in the eastern region is generally relatively stable, and only the internal development differences are consistent with the overall situation of the whole country, showing a trend of increasing year by year.

The curve distribution of Figure 1 (c) shows the characteristics of nearly double peaks, and the peak point moves around with time, showing a certain volatility, which shows that the development level of digital economy in the central region is extremely unstable. In addition, the tailing phenomenon on both sides of the curve distribution tends to increase with time, and the peak width is still large, indicating that the difference of development level in the central region is large.

The curve in Figure 1 (d) shows a unimodal form, and the peak value decreases year by year, indicating that the proportion of cities with a low level of development in the western region is decreasing with time. At the same time, it is obvious that the peak width of the curve distribution is gradually increasing, and the tail phenomenon on both sides of the distribution is significantly aggravated, which shows that the difference in the development level of digital economy in the western region is expanding year by year.

To sum up, the whole country shows a positive growth trend, and the eastern region is consistent with the overall, also showing a positive growth trend. While the central region development is more unstable, the polarization is more obvious. The overall level of the western region is relatively low, but it still shows a positive growth trend and has the development potential.

3.2Analysis Of The Spatial Characteristics Of The Development Level Of The Digital Economy

Taking the digital economy development index of 30 major provinces and cities from 2011 to 2020 as the object, Stata software is used to measure and analyze the spatial correlation. First, the weight matrix of economic distances was constructed to subjected the data to global spatial autocorrelation analysis of univariate Moran's I, and the test results are shown in Table 3.

Table 3. Global Moran's I Index of the Digital Economy in 2011-2020

Year	Moran's I index	P	Z
2011	0.080	0.064*	1.522
2012	0.096	0.041**	1.745
2013	0.096	0.039**	1.765
2014	0.11	0.027**	1.935
2015	0.127	0.015**	2.166
2016	0.118	0.018**	2.092
2017	0.111	0.022**	2.02
2018	0.109	0.024**	1.986
2019	0.106	0.027**	1.928
2020	0.104	0.029**	1.892

**The * and * * in Table 3 are significant at 10% and 5%, respectively*

As can be seen from Table 3, the Moran's I values of the digital economy development level in all provinces and cities from 2011 to 2020 all passed the significance test, and there was an overall positive spatial autocorrelation. In addition, the global Moran's I index of the development level of digital economy has shown a rising trend with time since 2011, which shows that the development level of China's digital economy with time.

According to the above test results, as shown in Figure 2, a scatter plot of local Moran's I index is drawn to further illustrate the spatial agglomeration pattern of the development level of digital economy in specific provinces and cities. From Moran's I scatter chart, the figure each scatter mainly located in the third quadrant, followed by the first quadrant, that most areas of the digital economy development index level is low-low clustering or high-high clustering, and most provinces and cities belong to low-low clustering, can think the provinces and cities and its surrounding areas of digital economy development level in space presents a certain positive correlation.

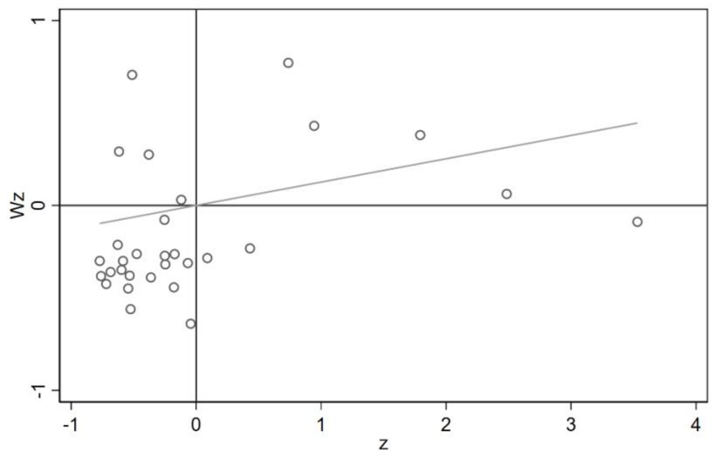

Figure 2. Local Space Autocorrelation Analysis Moran's I Scatter Plot (2020)

Specifically, Zhejiang, Beijing, Shanghai and Jiangsu are always in the first quadrant, belonging to high-high cluster provinces, frequent economic investment activities, high level of technological innovation, abundant human resources and high level of digital economy development, while internal digital economy development is closely related and deepens the degree of high-high agglomeration; Tianjin, Fujian and Inner Mongolia are always in the second quadrant, belonging to low-high cluster provinces, the level of digital economy development is relatively low, but in the same time, they are also influenced and driven to a certain extent.

Chongqing, Anhui, Yunnan, Gansu, Xinjiang, Guangxi, Guizhou, Hainan, Shanxi, Hebei, Qinghai, Heilongjiang, Ningxia, Jiangxi, Hubei, Hunan are always in the third quadrant, Province belonging to the low-low clustering, Most of these are in the western region, where the digital economy is relatively low, These provinces are remote, or have poor economic and environmental conditions, Less internal digital economy linkage, The digital economy is developing relatively slowly; besides, Guangdong is in the fourth quadrant for most years in 2011 and in 2020, Belongs to the high-low cluster, Its own digital economy development ability is relatively strong, But neighboring provinces have performed poorly, The surrounding provinces and cities cannot generate spillover effects to improve the level of digital economy. In addition, the change of local Moran's I in the development level of digital economy in some other provinces does not have obvious regularity.

4. CONCLUSION AND RECOMMENDATIONS

Based on the latest classification standards of core industries of digital economy, based on the panel data of 30 major provinces and cities from 2011 to 2020, this paper, 21 three-level indicators are selected to build the digital economy development index system. And using the nuclear density estimation, entropy method and Moran's I index, the overall level of

China's digital economy development, the development of digital economy, and the time and space of digital economy development distribution are analyzed, research found:

(1) nearly a decade, China's digital economy is developing rapidly, an average annual growth rate of 7.90%. However, there is obvious heterogeneity in space, and the development level of digital economy in the east, central and western regions is decreasing. For example, the average development index of digital economy in the east in 2020 is 4.5 times that of the west; (2) the development level gap of digital economy in different regions is increasing year by year, not showing the trend of convergence. Among them, the development of the eastern region is relatively stable, but the internal gap is increasing year by year. The development of the central region is extremely unstable and fluctuates obviously with the passage of time. The development level of the western region is low, and the internal differences are expanding year by year; (3) the development level of digital economy in various provinces and cities shows positive spatial autocorrelation, and shows obvious spatial agglomeration over time, that is, most regions show low-low clustering or high-high clustering. It further shows that the provinces (cities) with a high level of digital economy development have a certain positive role in driving the surrounding areas.

China's digital economy has a strong momentum of development, but from the perspective of spatial and temporal distribution, the problem of unbalanced and inadequate development in various regions is significant. Therefore, it is necessary to accelerate the policy layout of narrowing regional differences to promote the sustainable development of the digital economy. The following suggestions are as follows:

First, we should increase investment in digital innovation and pay attention to the training of digital talents. Increasing the investment in digital innovation can effectively balance the development of various sub-industries and lay a good foundation for the development of digital economy. The shortage of digital talents has become an important factor restricting the digital transformation of enterprises. Therefore, we must pay attention to the integration of production and talent, and vigorously cultivate the digital talents needed in the new era.

Second, strengthen regional cooperation to achieve common progress. The positive correlation in the space of China's digital economy shows that regional cooperation should be strengthened and actively build a mechanism for cross-regional coordinated development and complementary advantages. On the one hand, each region should consider its own development in the overall development of the whole country, combine with the existing major development strategies and regional coordinated development strategies, and implement the industrial policy of coordinated development of digital economy; on the other hand, each region should cooperate with each other to form a virtuous circle of mutual promotion. For example, regions with high level of digital economy development summarize their development experience, and then provide reference for regions with low level of development, so as to promote the development level of digital economy in backward regions with comparative advantages and realize the coordinated development among regions.

Third, we should take classified measures according to local conditions to cultivate a sound digital ecology. The government should formulate reasonable development policies according to the geographical location and industrial structure of the region. For example, Guangzhou, Beijing and other regions with high development level should implement regional development and driving development policies, so as to play a positive driving role in space.

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