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RESEARCH ON THE MEASUREMENT OF THE DEVELOPMENT LEVEL OF DIGITAL ECONOMY AND ITS INFLUENCING FACTORS

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ABSTRACT

The digital economy is an important component of China's economy, a key driving force for stable economic growth, and plays a leading and supporting role in economic and social development. This article constructs an evaluation index system for the development level of the digital economy from three dimensions: digital infrastructure construction, digital application development, and digital industrialization development. The vertical and horizontal leveling method was used to measure the level of digital economy development in 33 provinces and cities in China from 2013 to 2021. Analyze the influencing factors of China's digital economy development level using the spatiotemporal geographic weighted regression (GTWR) model. The results indicate that the development level of digital economy in various provinces and cities in China is uneven, showing obvious spatial agglomeration characteristics in the east, with a pattern of high in the east and low in the west. The penetration rate of mobile internet and the proportion of software business revenue to GDP have the greatest impact on the development level index of the digital economy. Suggest increasing the penetration rate of mobile internet and increasing software business revenue to promote the development of China's digital economy.

Keywords: Digital economy, vertical and horizontal leveling method, GTWR model, measurement, Iinfluencing factors

1. Introduction

The term 'digital economy' has existed since the 1990s. In 1995, Don Tapscott, an American economist known as the "father of the digital economy," elaborated on the impact of the Internet on the social economy in his book "The Digital Economy: Hope and Risks in the Age of Intellectual Interconnection." From then on, the concept of the digital economy entered the research field of theory and academia. Subsequently, works such as Nicholas Negroponte's "Being Digital" (1996) and Manuel Costell's "The Information Age: Economy, Society, and

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Culture" (1997) were successively published, and the concept of the digital economy became popular worldwide. From the perspective of the state, government, and government organizations, the concept of the digital economy was first proposed by the Organization for Economic Cooperation and Development in the 1990s. Afterward, governments around the world took measures to use the digital economy as a new driving force for economic growth. Since the 2008 financial crisis, many countries have formulated digital economy strategies to get out of the recession as soon as possible[1].

In recent years, China has also attached great importance to the significant role of the digital economy in leading economic growth and upgrading industrial structure. In March 2015, the Report on the Work of the Government proposed the "Internet Plus" action plan. In 2016, at the G20 Summit, China advocated the signing of the G20 Digital Development and Cooperation Initiative, which was the first time that the concept of "digital economy" was used in an official document of China, and for the first time, "digital economy" was included as an important topic in the G20 innovation and growth blueprint. The Report on the Work of the Government of 2017 pointed out that "promote the in-depth development of 'Internet plus' and accelerate the growth of the digital economy so that enterprises can benefit widely and the group can benefit generally." In October of the same year, the digital economy was included in the report of the 19th National Congress of the Communist Party of China. In recent years, China has deeply implemented the digital economy development strategy, and new-generation digital technology innovation is active and rapidly spreading, accelerating the deep integration with various industries and fields of the economy and society, effectively supporting the construction of a modern economic system and high-quality development of the economy and society. The China Internet Development Report points out that the digital economy has become a key driving force for stable economic growth.

Entering the 21st century, countries and international organizations have conducted continuous exploration of the measurement of the digital economy. From the perspective of statistical measurement methods, there are generally two approaches to existing research: the direct method, which measures the scale of digital economy development by defining the scope of relevant industries in the digital economy and directly measuring the added value of the digital economy industry. The second is the index method, which calculates the development of the digital economy by constructing a multi-dimensional evaluation index system and compiling a digital economy development index. Due to the difficulty of using a single aggregate indicator to reveal and reflect the specific development status of the digital economy using the direct method, the establishment of a comprehensive evaluation index system can reflect the quality of digital economy development from multiple dimensions and measure the level of digital economy development from different perspectives, most research characterizes the scale of the digital

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economy by compiling a digital economy development index. For example, Li Zhiqiang and Liu Ying constructed and measured a digital economy development index from three dimensions: infrastructure construction, digital applications, and digital industry development, and analyzed its influencing factors using the GWR model [2]. Yanning Yang and Chang Dong used factor analysis to analyze the development level of China's digital economy from three dimensions: infrastructure construction, research and innovation capabilities, and current economic development. Based on the scores of their secondary indicators, suggestions were proposed [3]. Tang Luyang, Lu Bangke, and Tian Tianhai measured the development level of the digital economy from four dimensions of digital infrastructure, digital innovation capability, digital industry scale, and digital technology application, and analyzed China's regional differences using Theil index and kernel density estimation methods [4]. Wang Zhong and Shi Peibei measure the level of digital economy development from three dimensions: digital industrialization, industrial digitization, and information infrastructure [5]. Deng Xue, Liu Yuying, and Xiong Ye constructed a digital economy indicator system consisting of 20 indicators from four aspects: basic, technological, integrated, and service-oriented. Based on the improved entropy method, deficiencies were identified and suggestions were proposed [6].

In summary, experts and scholars have continuously explored the connotation and statistical measurement of the digital economy from various dimensions, laying a solid foundation for further research on the digital economy. However, the indicator system covered is not yet comprehensive. In view of this, this article uses frequency analysis to measure the development level of the digital economy from three dimensions: digital infrastructure construction, digital application development, and digital industrialization development. The GTWR model is used to analyze its driving factors from both spatial and temporal perspectives.

The rest of this article is structured as follows: Section 2 uses the frequency analysis method and combines it with the definition of the digital economy in the "Statistical Classification of the Digital Economy and Its Core Industries (2021)" to construct an evaluation index system for the development level of the digital economy. Next, we introduced the vertical and horizontal leveling method and the spatiotemporal geographic weighted regression model. Then, in Section 4, analyze the level of digital economy development in various provinces of China. Next, in Section 5, we will analyze the driving factors of the development level of the digital economy based on the GTWR model. Then, in Section 6, based on the conclusions drawn in Sections 4 and 5, provide some suggestions for the development of China's digital economy.

2. Construction of Index System

The digital economy is a complex system, and to this day, there is still controversy about measuring the level of development of the digital economy. Therefore, to make the selected indicators as scientific and comprehensive as possible, this article searched for relevant references and analyzed the frequency of indicators based on the searched literature. Search for literature with keywords "digital economy" and "measurement" from 2010 to 2023 in the core collection of Web of Science and CNKI, remove literature with weak correlation, and obtain 1061 articles. Select 30 Chinese literature with the highest citation and 15 English literature as reference samples from the selected literature, and sort them according to the frequency of occurrence of the indicators to obtain a reference indicator set.

Based on the principles of data accessibility and operability, combined with the definition of the digital economy in the "Statistical Classification of the Digital Economy and Its Core Industries (2021)", an evaluation index system for the development level of China's digital economy has been constructed from three aspects: digital infrastructure construction, digital application development, and digital industrialization development, as shown in Table 1. The data mainly comes from statistical yearbooks such as the China Statistical Yearbook from 2013 to 2021, statistical yearbooks of various provinces and cities in China, and the China Electronic Information Industry Statistical Yearbook. Some of the data comes from data published by the National Bureau of Statistics. Missing values are filled in using interpolation or linear regression methods.

Table. 1 The evaluation index system of digital economy

Primary indicators	Secondary indicators	unit	method of calculation
Digital infrastructure construction	Mobile phone exchange capacity	10000 households	——
	Number of internet broadband access ports	Ten thousand pcs	——
	Fiber optic cable line length	Kilometers	——
	Number of mobile phone base stations	Ten thousand pcs	——
	Number of IPv4 addresses	Ten thousand	——
	Number of domain names	Ten thousand	——
Development of digital applications	Number of enterprises with e-commerce transaction activities	pcs	——
	Number of websites owned by every hundred enterprises	pcs	——
	Number of computers used per hundred people	Set	——

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Development of digital industrialization	The proportion of enterprise e-commerce sales to GDP	%	Enterprise e-commerce sales/GDP
	Mobile Internet penetration rate	%	Number of mobile internet users/total population at the end of the year
	Mobile phone penetration rate	%	——
	labor input	%	Number of employees in the software and information service industry/total population at the end of the year
	Proportion of product revenue to GDP	%	Software business revenue/GDP
	R&D manpower investment	%	Number of R&D personnel in the software and information service industry/total population at the end of the year
	R&D intensity	%	Full time equivalent of R&D personnel in the software and information service industry
	Number of patent authorizations per 10000 people	pcs	Number of software and information service industry patent authorizations/total population at the end of the year
	R&D investment	%	Internal expenditure of R&D funds for software and information services industry/GDP

3. Research Method

3.1 Data Processing

The population structure evaluation index system and the digital economy evaluation index system involve multiple indicators, with different units and dimensions, resulting in no-comparability between different indicators. Therefore, before calculating, it is necessary to perform dimensionless processing on the raw data of each indicator to eliminate the dimensional impact of the original variables through data transformation. Due to the advantages of simplicity, accuracy, the minimal impact of changes in operating conditions on results, and less strict requirements for sample size, the normalized dimensionless method is used in this paper to process the raw data obtained, to unify the dimensions between various indicators and avoid cross-influence. Beacause all indicators in the indicator system constructed in this article a re-positive indicators, the data processing method is as follows[7]:

$$x_{ijk}^{*} = \frac{x_{ijk} - \min(x_{ijk})}{\max(x_{ijk}) - \min(x_{ijk})}, \quad (1)$$

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In equation (1), $i = 1, 2, \cdots, 31$; $j = 1, 2, \cdots, 18$; $k = 1, 2, \cdots, 9$; x_{ijk} represents the value of the i-th indicator in the j th province in the k th year; $\max(x_{ijk})$ and $\min(x_{ijk})$ represent the maximum and minimum values of the j th indicator in all provinces and years, respectively.

3.2 Weight

The Vertical and Horizontal Leveling Method (VHSD) can reflect both the differences between different regions at a certain moment horizontally and the overall distribution of each region vertically. The principle of determining weights is to maximize the gap between the evaluated objects, which is to use the sum of the squares of the total deviations of $y_t(t_k)$ and θ^2 to represent the gap between the evaluated objects, The comprehensive evaluation index and weight calculation formula are:

$$y_i(t_k) = \sum w_j x_{ij}^*(t_k), \tag{2}$$

Among them, w_j is the weight of the j th indicator, $x_{ij}^*(t_k)$ is the indicator value of the j th and k th year of the i th province after the Indicator value, and t_k is the k th year. The calculation process of $w = \{w_j\}$, $j = 1, 2, \cdots, 18$ is as follows:

First, construct the sum of squares of total deviations θ^2, calculated using the formula:

$$\theta^2 = \sum_{k=1}^{N} \sum_{i=1}^{n} (y_i(t_k) - \bar{y})^2, \tag{3}$$

Second, synthesize equations (2) and (3) to simplify the expression of θ^2:

$$\theta^2 = w' \left[\sum_{k=1}^{N} x^{*\prime}(t_k) x^*(t_k) - nN \overline{x^*}\, \overline{x^*}' \right] w, \tag{4}$$

Among them,

$$x^*(t_k) = \begin{bmatrix} x_{11}^*(t_k) & \cdots & x_{1m}^*(t_k) \\ \vdots & \ddots & \vdots \\ x_{n1}^*(t_k) & \cdots & x_{nm}^*(t_k) \end{bmatrix}, \tag{5}$$

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$\overline{x^*}$ is the mean vector of the indicator, $w = \begin{pmatrix} w_1 & w_2 & \cdots & w_m \end{pmatrix}'$. After sorting, equation (3) can also be expressed in the following form:

$$\theta^2 = w'Hw, \tag{6}$$

$$H = \sum x^{*\prime}(t_k)x^*(t_k) - nN\overline{x^*}\,\overline{x^*}', \tag{7}$$

If a component of w is negative, then w can be solved by the following programming problem, that is, selecting w so that:

$$\begin{aligned} &\max w^T Hw, \\ &s.t.\|w\| = 1. \end{aligned} \tag{8}$$

3.3 Geographically and Temporally Weighted Regression.

In traditional economic theory, the study of the relationship between the dependent variable and the independent variable mostly adopts the Ordinary Least Squares Method (OLS), ignoring the spatial effects between data. Although the Geographically Weighted Regression (GWR) model compensates for the shortcomings of the OLS method, it can only be used for cross-sectional data. The Geographically and Temporally Weighted Regression (GTWR model) compensates for the shortcomings of OLS and GWR models by incorporating both time and space into the control variables of the regression model. The specific calculation formula for the GTWR model is as follows:

$$y(u_i,v_i,t_i) = \beta_0(u_i,v_i,t_i) + \sum_{j=1}^{k} \beta_j(u_i,v_i,t_i)x_i(u_i,v_i,t_i) + \varepsilon_i, \tag{9}$$

Among them, y_i and $x_{i1}, x_{i2}, \cdots, x_{ij}$ are the dependent and explanatory variables at the space-time position (u_i,v_i,t_i), (u_i,v_i) is the longitude and latitude coordinates of the study area, t_i is time, $\beta_0(u_i,v_i,t_i)$ is a constant term, ε_i is a random error, and $\beta_j(u_i,v_i,t_i)$ is the regression coefficient of the k th explanatory variable.

4. Evolution of the Development Level of the Digital Economy

Based on the China Statistical Yearbook, Statistical Yearbooks of various provinces and cities, and other statistical yearbooks, the R software is used to assign weights to the indicators using the VHSD method. Then, the calculated weights are combined with the weighted values of each

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indicator in the digital economy evaluation index to calculate the digital economy development level index of each province and city, as shown in Table 2.

Table. 2 Digital Economy Development Level Index of Various Provinces and Cities in China from 2013 to 2021

Province	2013	2014	2015	2016	2017	2018	2019	2020	2021
Beijing	41.10	50.39	52.86	54.67	56.61	58.88	62.54	65.37	69.7
Guangdong	40.68	45.57	47.84	50.51	52.84	57.35	60.25	60.46	62.51
Shanghai	32.59	37.25	38.17	39.86	41.2	44.81	47.8	49.54	51.47
Zhejiang	33.95	35.99	39.12	40.45	43.71	46.86	48.25	48.93	49.62
Jiangsu	29.05	31.40	33.46	35.41	36.21	43.13	46.28	46.62	46.96
Shandong	24.44	26.90	28.87	32.17	34.89	36.79	37.55	39.35	40.92
Sichuan	23.12	25.94	28.50	31.26	33.43	35.93	39.43	39.72	40.45
Tianjin	24.53	26.61	29.30	30.37	29.82	31.37	31.27	34.15	36.84
Hebei	19.28	21.42	23.04	26.01	29.28	31.56	32.93	34.08	35.27
Henan	16.87	20.16	21.91	24.22	25.77	27.62	29.85	30.42	32.00
Hubei	17.49	19.98	21.61	23.48	25.30	27.05	28.7	30.43	31.26
Fujian	23.11	23.4	24.62	26.00	26.64	28.95	29.97	29.74	31.08
Anhui	17.81	19.33	21.80	23.50	25.69	27.32	28.84	30.46	30.92
Hunan	15.36	17.59	18.70	20.34	23.70	25.65	27.01	28.98	30.38
Chongqing	14.01	16.32	17.78	19.82	21.78	24.28	25.35	26.42	30.22
Liaoning	19.81	21.52	27.24	24.48	26.08	26.66	27.47	28.46	29.23
Shaanxi	18.12	20.19	20.87	22.64	24.19	25.87	26.68	27.6	28.75
Jiangxi	11.99	13.54	15.06	15.18	18.85	21.17	23.28	25.14	25.68
Guangxi	10.59	12.02	9.32	10.67	17.21	20.82	22.4	24.68	25.35
Heilongjiang	13.58	15.98	17.69	19.51	21.63	22.06	24.27	25.44	25.01
Yunnan	13.31	15.59	16.97	17.05	18.37	20.77	22.97	22.5	23.18
Inner Mongolia	16.39	16.99	17.49	18.92	20.92	20.92	21.23	22.74	23.04
Guizhou	11.77	13.67	13.85	15.79	17.18	19.63	21.41	21.22	22.62
Jilin	12.73	15.25	15.15	15.80	18.23	19.40	19.40	21.38	22.02
Shanxi	12.53	14.14	14.47	15.25	16.26	17.83	18.39	20.07	20.68
Gansu	10.82	12.36	13.61	14.78	17.48	18.57	18.71	19.43	20.08
Xinjiang	12.73	13.49	14.29	14.41	14.98	18.04	17.41	17.9	19.08
Hainan	15.98	17.94	17.93	18.66	19.72	20.00	17.35	17.15	18.38
Ningxia	12.55	14.03	13.54	15.22	16.97	18.36	16.65	17.42	17.93
Qinghai	11.36	12.33	14.78	14.53	14.63	16.12	15.78	16.46	17.45
Tibet	8.07	11.28	11.88	14.18	14.59	14.55	15.51	13.14	13.55

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The results show:

(1) From 2013 to 2021, the development level of the digital economy in various provinces and cities in China was uneven, showing obvious spatial agglomeration characteristics in the east, showing a pattern of high in the east and low in the west. The regions with high levels of digital economy development index are mainly concentrated in the eastern region of China, with Beijing, Jiangsu Province, Zhejiang Province, and Guangdong Province having the highest level of digital economy development index. The regions with lower levels of digital economy development index are mainly distributed in western China, with Tibet Autonomous Region having the lowest level of digital economy development index.

(2) The development level of the digital economy in Guangdong Province is significantly higher than that of other provinces and cities, mainly because Guangdong Province has a strong communication infrastructure, solid technology, talent, and industrial foundation, high industrial concentration ratio, large scale, good foundation, and perfect industrial chain layout, which is conducive to the development of digital economy in Guangdong Province.

(3) The changes in the digital economy development level index vary among provinces from 2013 to 2021. The digital economy development water index of Tianjin, Hunan Province, Guangxi Zhuang Autonomous Region, Hainan Province, and Tibet Autonomous Region shows a fluctuating trend, while the digital economy development level index of other provinces and cities shows an overall upward trend.

(4) From 2013 to 2021, there was no significant spatial pattern change in the development level index of the digital economy. Overall, except for the Tibet Autonomous Region, the level of digital economy development in all provinces and cities is showing an upward trend. The main reason why the Tibet Autonomous Region has maintained a low level of development is that its understanding of the digital economy is relatively lagging, some units have not fully understood the importance of the digital economy for Tibet's development, the industrial correlation and spatial and temporal layout between the information market entities have not yet formed an effective chain form, the upstream and downstream extension of the industrial chain is limited, and business connections, division of labor and cooperation between enterprises on the chain are limited Insufficient complementary interaction and collaborative operation, and insufficient upstream and downstream supporting resources in the industrial chain.

5. Analysis of Driving Factors for the Development Level of Digital Economy Based on GTWR Model

To avoid the pseudo-regression phenomenon and ensure the stability of the GTWR model, the SPSS software was used to conduct a multicollinearity test on each explanatory variable, and the

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variables with a variance expansion factor (VIF) greater than 10 were excluded. The final indicators were: mobile phone switch capacity (x_1), cable line length (x_2), number of domain names (x_3), number of websites owned by each enterprise (x_4), mobile Internet penetration rate (x_5), and the proportion of software business income in GDP (x_6). The GTWR model established based on these indicators is:

$$\begin{aligned} y_i = {} & \beta_0(u_i,v_i,t_i) + \beta_1(u_i,v_i,t_i)x_{1i} + \beta_2(u_i,v_i,t_i)x_{2i} + \beta_3(u_i,v_i,t_i)x_{3i} \\ & + \beta_4(u_i,v_i,t_i)x_{4i} + \beta_5(u_i,v_i,t_i)x_{5i} + \beta_6(u_i,v_i,t_i)x_{6i}\varepsilon_i \end{aligned} \tag{10}$$

This article uses AICc as the bandwidth selection method and Fixed as the kernel function in ArcGIS. The digital economy development level index is selected as the dependent variable, and the GTWR plugin is run. The output diagnostic indicators are shown in Table 3. The results show that the optimal bandwidth of the GTWR model is 1.9881, and the sum of squared residuals is 0.3071. The Goodness of fit of R^2 and adjusted R^2 were 0.9217 and 0.9200 respectively, both close to 1; The significance level is 0.033, which is less than 0.05, indicating a high fitting degree of the model to the data. The model can explain 92.17% of the changes in the digital economy development level index, and the overall fitting effect of the model is very good. The OLS model has a smaller R^2 than the GTWR model, so the GTWR model was chosen to analyze the influencing factors of digital economy development.

Table. 3 Parameter Result

Parameter	GTWR	OLS
Model bandwidth	1.9881	——
Residual Sum of Squares	0.3071	0.3103
significance	0.033	——
AICc	-1090.91	-1091.80
R^2	0.9217	0.9206
adjusted R^2	0.9200	——

To deeply analyze the influencing factors of the development level of the digital economy, statistical descriptive analysis was conducted on the regression coefficients of various indicators in the GTWR model (see Table 4).

Table. 4 Estimation Results of Regression Coefficients for Various Indicators in the GTWR Model

Variable	Maxe	Min	Upper quartile	Lower quartile	mean	S.d.
x_1	0.1654	0.1629	0.1644	0.1649	0.1649	0.0005

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x_2	0.1008	0.0993	0.0996	0.1000	0.0998	0.0003
x_3	0.0792	0.0754	0.0769	0.0781	0.0775	0.0009
x_4	0.0971	0.0953	0.0959	0.0964	0.0961	0.0004
x_5	0.2696	0.2538	0.2564	0.2604	0.2588	0.0032
x_6	0.4937	0.4894	0.4906	0.4920	0.4913	0.0009

The results show that the capacity of mobile telephone switches, the length of optical cable lines, the number of domain names, the number of websites owned by each enterprise, the penetration rate of mobile Internet, and the proportion of software business income in GDP are significantly positively correlated with the development level of the digital economy, and the upper quartile and lower quartile of their regression coefficients are greater than 0. The penetration rate of mobile internet and the proportion of software business income to GDP have the greatest impact on the development level index of the digital economy. Therefore, increasing the penetration rate of mobile internet and increasing software business income may be the main means to promote the development of the digital economy.

6. Conclusions and Recommendations

This article constructs an evaluation index system for the development level of the digital economy from three aspects: digital infrastructure construction, digital application development, and digital industrialization development. The index is weighted using the vertical and horizontal leveling method to calculate the digital economy development level index of 33 provinces in China from 2013 to 2021; Use the GTWR model conducts regression analysis on the development level of China's digital economy and analyzes the influencing factors of China's digital economy development level. The specific conclusions are as follows: (1) The development level of the digital economy in various provinces and cities in China is uneven, showing obvious spatial agglomeration characteristics in the east, showing a pattern of high in the east and low in the west. The development level index of the digital economy in most provinces and cities shows an overall upward trend. The penetration rate of mobile internet and the proportion of software business revenue to GDP have the greatest impact on the development level index of the digital economy.

In response to the current status and influencing factors of China's digital economy development, this article believes that increasing the penetration rate of mobile internet and increasing software business revenue are important factors that urgently need to be addressed to promote the development of China's digital economy.

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