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Coupling Coordination and Dynamic Analysis of the Integration and Development of Digital Economy and Real Economy

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Abstract: *The deep integration of digital economy and real economy is an inherent requirement and strategic direction for the high-quality development of China's economy. The article is based on panel data from 30 provinces from 2013 to 2022 to measure the level of coordinated development, regional differences, and dynamic evolution of the integration of data and reality. Research has shown that the level of integration between data and reality has been increasing year by year, but the overall development of the digital economy lags behind that of the real economy; The problem of imbalanced development in the integration of data and reality at the regional and provincial levels is prominent, showing a gradient feature of "high in the east and low in the west"; The regional differences in the level of coupling and coordination between China's digital economy and the real economy are the main factors leading to the formation of overall differences; The coupling and coordination level of digital economy and real economy in the national and western regions shows a weak polarization phenomenon, while the eastern and central regions do not show polarization phenomenon.*

Keywords: *Digital economy, Real economy, Coupled co scheduling*

1. Introduction

The digital economy is an important frontier of technological innovation and is related to the overall development of the country. The report of the 20th National Congress of the Communist Party of China pointed out the need to accelerate the development of the digital economy, promote the deep integration of the digital economy and the real economy, and build a digital industry cluster with international competitiveness. Accelerating the development of the digital economy, promoting the deep integration of the digital economy and the real economy, is of great significance in promoting the construction of a new development pattern, a modern economic system, and building new national competitive advantages.

In the existing research on the integration of data and reality, scholars have conducted in-depth discussions on the relationship between the digital economy and the real economy. On a theoretical level, Zheng Qiongjie et al. pointed out that under the triple pressure of demand contraction, supply shock, and weakened expectations in China's economic development, promoting the integration of data and reality requires the construction of three major systems: supply support, demand pull, and operational guarantee[1]. Chen Xi analyzed the specific path of deep integration between the digital economy and the real economy from three aspects: product layer, enterprise layer, and industry layer, and constructed a research framework of "digital real integration"[2]. On an empirical level, Hu Xijuan et al. used the combination weighting method to measure and point out that the current level of "digital real integration" development in China is on the rise, and it shows spatial imbalance [3]; Guo Han et al. (2022) used a coupled coordination degree model to conclude that the coordinated development level of "digital real integration" in various provinces continues to deepen, but the development level of the real economy in most provinces is higher than that of the digital economy [4]. There is still room for further research on the coordinated development of the integration of data and reality, although existing research has established a certain theoretical foundation. This article is based on panel data from 30 provinces in China from 2013 to 2022, analyzing the coordinated development level, regional characteristics, and dynamic evolution laws of "data real integration".

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2. Research Design

2.1. Construction of indicator system

Coupling coordination is a synthetic concept in economics [5], which describes the degree of interaction between systems and subsystems, including two aspects: coupling degree and coordination degree. The construction of a coordinated development indicator system for the integration of data and reality needs to be explored from two aspects: the digital economy and the real economy. In order to objectively and comprehensively evaluate the coupling and coordination relationship between the digital economy and the real economy, this article draws on the research of Huang Congying (2019)[6] and Guan Huijuan et al. (2020)[7] to construct evaluation indicators for the real economy from four dimensions: entity structure, entity benefits, entity environment, and entity innovation. Evaluation indicators for the digital economy are established from three dimensions: digital infrastructure, digital applications, and digital innovation. Finally, an evaluation indicator system for the coordinated development of "digital real integration" is obtained.

2.2. Research Methods

This article uses the entropy method [8] to measure the comprehensive development level of the digital economy and the real economy respectively. Referring to the research of Tang Xiaohua et al [9], a coupling coordination degree model is used to quantitatively analyze the coupling degree and coupling coordination degree of "numerical real fusion". The dynamic evolution of the comprehensive development level of the digital economy and the real economy was characterized using kernel density estimation method.

2.2.1. Coupled co scheduling model

The first step is data standardization. To enhance the comparability of indicator data, the original indicator data was standardized, and the standardized results are as follows:

Among them, z_{ai} and z_{bi} respectively represent the original values of the i indicator of the digital economy system and the real economy system, $i = 1,2,\cdots,n$

Step 2, calculate the comprehensive development level of the subsystem:

$$U_k = \sum_{i=1}^{n} \theta_{ki} z'_{ki}, \sum_{i=1}^{n} \theta_{ki} = 1$$

Among them, θ_{ai}, θ_{bi} represents the weight of the k-th indicator of the digital economy system and the real economy system. In order to avoid human interference, this article uses information entropy to determine the weight.

Step 3, calculate coupling degree and coupling co scheduling:

$$C(U_1,U_2,\cdots,U_L) = n \times [U_1,U_2,\cdots,U_L / (U_1+U_2+\cdots+U_L)^L]^{1/L}$$

Among them, C_{ab} represents the coupling degree between subsystems, with a value range of 0 and1, L represents the number of subsystems, and at that time $L = 2$, there are:

$$C_{ab} = 2 \times [U_a U_b / (U_a + U_b)^2]^{1/2}$$

Among them, C_{ab} represents the coupling degree value between the digital economy system and the real economy system. The degree of coupling can only reflect the magnitude of the interaction between systems, but cannot characterize whether two systems promote each other at a high level or constrain each other at a low level. Therefore, it is necessary to introduce a coupled coordination model to accurately evaluate the interaction and coordination relationships between systems. The coupling coordination model is as follows:

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$$D_{ab} = (C_{ab} \times T_{ab})^{1/2}$$
$$T_{ab} = \alpha U_a + \beta U_b$$

D_{ab} Represents the coupling coordination degree value, with a range of 0 and1, T_{ab} Comprehensive evaluation indicators representing the system.

2.2.2. Dynamic Evolution Model

The kernel density estimation method (2021) is a non parametric statistical method used to estimate the shape of the probability density function. To analyze the distribution, trend, extensibility, and polarization trend of the coordination relationship between digital economy and real economy in different regions, this paper selects kernel density estimation method to carry out relevant research. Assuming $f(x)$ is the density function of the coordinated relationship between the digital economy and the real economy:

$$f(x) = \frac{1}{Nh}\sum_{i=1}^{N} K(\frac{X_i - x}{h})$$

This article selects the commonly used Gaussian kernel density function to estimate the distribution dynamics, and the expression is:

$$k(x) = \frac{1}{\sqrt{2\pi}}\exp(-\frac{x^2}{2})$$

2.3. Data sources

This paper uses the panel data of 30 provinces in China (excluding Xizang, Hong Kong, Macao and Taiwan) from 2013 to 2022. The data mainly comes from the annual China Statistical Yearbook, China Industrial Statistical Yearbook, China Information Yearbook, China Information Industry Yearbook, and Wind database. Some missing data is filled in using interpolation method.

3. Analysis of Empirical Results

3.1. Integration and Development Level of Digital Economy and Real Economy

This article uses the entropy method to measure the level of coordinated development between the digital economy and the real economy in 30 provinces of China from 2013 to 2022(Table 1).

We can see that the growth rate has increased from 0.355 in 2013 to 0.471 in 2023, with an average annual growth rate of 3.28%, indicating that China's overall coordinated development of "digital real integration" is improving, but the level of coupling coordination is not high, and there is still significant room for improvement.

From the perspective of the average ranking of provinces, Guangdong, Jiangsu, Beijing, Zhejiang, and Shandong rank among the top five provinces in terms of the average coordination level of "numerical real integration", and are generally in a highly coordinated stage or above. The provinces with the lowest average level of coordinated development in the integration of numbers and reality are Qinghai, Ningxia, Hainan, Xinjiang, and Gansu.

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Table 1: Coordinated Development Level of "Digital Real Integration" in Various Provinces from 2013 to 2022

Province	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Mean Value
Beijing	0.49	0.51	0.52	0.55	0.57	0.58	0.62	0.63	0.65	0.66	0.58
Tianjin	0.36	0.37	0.38	0.39	0.40	0.41	0.41	0.42	0.42	0.43	0.40
Hebei	0.36	0.37	0.39	0.40	0.41	0.42	0.44	0.46	0.47	0.48	0.42
Shanxi	0.30	0.32	0.33	0.34	0.33	0.35	0.36	0.37	0.38	0.39	0.35
Neimenggu	0.30	0.30	0.32	0.33	0.32	0.33	0.34	0.35	0.37	0.38	0.33
Liaoning	0.40	0.42	0.44	0.44	0.44	0.43	0.44	0.45	0.45	0.46	0.44
Jilin	0.32	0.33	0.33	0.34	0.35	0.35	0.37	0.38	0.41	0.41	0.36
Heilongjiang	0.32	0.32	0.34	0.34	0.35	0.35	0.37	0.37	0.38	0.39	0.35
Shanghai	0.46	0.47	0.49	0.50	0.51	0.53	0.54	0.55	0.57	0.57	0.52
Jiangsu	0.55	0.57	0.59	0.60	0.61	0.62	0.63	0.65	0.68	0.69	0.62
Zhejiang	0.47	0.49	0.51	0.52	0.53	0.55	0.56	0.58	0.60	0.62	0.54
Anhui	0.35	0.37	0.38	0.39	0.40	0.42	0.43	0.45	0.47	0.49	0.42
Fujian	0.39	0.40	0.41	0.42	0.43	0.45	0.46	0.47	0.49	0.49	0.44
Jiangxi	0.32	0.34	0.35	0.36	0.36	0.38	0.39	0.41	0.43	0.44	0.38
Shang dong	0.45	0.47	0.49	0.51	0.51	0.53	0.54	0.56	0.57	0.59	0.52
Henan	0.37	0.40	0.42	0.42	0.43	0.44	0.46	0.48	0.49	0.51	0.44
Hubei	0.36	0.38	0.40	0.42	0.43	0.44	0.46	0.47	0.49	0.50	0.44
Hunan	0.35	0.37	0.38	0.39	0.40	0.41	0.43	0.44	0.46	0.48	0.41
Guangdong	0.57	0.59	0.61	0.62	0.63	0.65	0.68	0.71	0.73	0.75	0.65
Guangxi	0.31	0.31	0.33	0.34	0.35	0.36	0.38	0.39	0.41	0.43	0.36
Hainan	0.26	0.26	0.28	0.28	0.29	0.30	0.30	0.31	0.33	0.37	0.30
Chongqing	0.33	0.34	0.35	0.37	0.38	0.40	0.42	0.43	0.44	0.45	0.39
Sichuan	0.38	0.40	0.41	0.43	0.44	0.46	0.48	0.50	0.52	0.54	0.46
Guizhou	0.28	0.28	0.30	0.31	0.31	0.33	0.35	0.37	0.38	0.40	0.33
Yunnan	0.29	0.30	0.30	0.31	0.32	0.33	0.35	0.37	0.39	0.41	0.34
Shanxi (xian)	0.33	0.35	0.36	0.37	0.38	0.40	0.40	0.43	0.45	0.47	0.39
Gansu	0.28	0.29	0.30	0.31	0.31	0.32	0.34	0.34	0.36	0.37	0.32
Qinghai	0.22	0.23	0.24	0.26	0.28	0.28	0.28	0.29	0.29	0.31	0.27
Ningxia	0.23	0.24	0.26	0.27	0.28	0.28	0.30	0.30	0.31	0.31	0.28
Xinjiang	0.26	0.27	0.28	0.29	0.30	0.31	0.31	0.33	0.35	0.36	0.31
Mean Value	0.36	0.37	0.38	0.39	0.40	0.41	0.43	0.44	0.46	0.47	

3.2. Regional Differences in the Integration and Coordination of Digital Economy and Real Economy

The coordinated development level of "digital real integration" at the regional level is shown in Table 2. From 2013 to 2022, the coupled coordination level showed a gradient pattern of eastern>central>western. The overall level of coupling and coordination among the three major regions shows a growth trend, with the average annual growth rates of 2.83%, 3.39%, and 3.85% in the eastern, central, and western regions, respectively.

Table 2: Coordination level of "digital real integration" development in various regions from 2013 to 2022

Region	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
East	0.43	0.45	0.46	0.48	0.48	0.50	0.51	0.52	0.54	0.56
Middle	0.34	0.35	0.37	0.38	0.38	0.39	0.41	0.42	0.44	0.45
West	0.29	0.30	0.31	0.33	0.33	0.35	0.36	0.37	0.39	0.40
Nationwide	0.36	0.37	0.38	0.39	0.40	0.41	0.43	0.44	0.46	0.47

In order to deeply study the regional differences and sources of the coupling coordination between the digital economy and the real economy in China, this article uses the Dagum Gini coefficient principle to calculate the overall, intra regional, and inter regional Gini coefficients of the coupling coordination between the digital economy and the real economy in 30 provinces of China from 2013 to

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2022, as well as the sources of overall differences, as shown in Table 3.

Table 3: Differences in the Coordination Degree of "Digital Real Integration" Development in Different Regions from 2013 to 2022

Year	Total	Regional differences			Regional differences			Contribution rate (%)		
		East	Middle	west	East-Middle	East-west	Middle-west	In region	Inter regional	Supervariable density
2013	0.13	0.11	0.04	0.09	0.15	0.21	0.09	22.71	69.53	7.76
2014	0.14	0.11	0.05	0.08	0.14	0.21	0.10	22.87	69.18	7.95
2015	0.13	0.11	0.05	0.08	0.14	0.20	0.10	23.10	68.74	8.16
2016	0.13	0.11	0.05	0.08	0.14	0.20	0.09	23.24	67.88	8.88
2017	0.13	0.11	0.05	0.08	0.14	0.20	0.09	23.71	66.66	9.63
2018	0.13	0.12	0.05	0.08	0.14	0.19	0.09	24.08	65.77	10.15
2019	0.13	0.12	0.05	0.09	0.14	0.19	0.09	24.65	64.13	11.22
2020	0.13	0.12	0.06	0.09	0.14	0.19	0.09	25.37	62.26	12.37
2021	0.13	0.12	0.05	0.09	0.13	0.18	0.09	26.21	60.64	13.15
2022	0.12	0.12	0.06	0.09	0.13	0.18	0.09	26.55	61.08	12.37

(1) Overall differences, as shown in Table 3, the overall Gini coefficient of coupled co scheduling during the inspection period ranged from 0.124 to 0.135, showing a decreasing trend. The overall Gini coefficient decreased from 0.134 in 2013 to 0.124 in 2022, a decrease of 7.8%.

(2) The Gini coefficients of the coordination degree of the integration of data and reality in the three major regions show varying degrees of upward trend, but are lower than the national level. The regional differences, from large to small, are in the eastern, western, and central regions, with average Gini coefficients of 0.115, 0.085, and 0.050.

(3) The regional differences, in numerical terms, are East West, East Middle, and Central West, with average Gini coefficients of 0.195, 0.139, and 0.093.

(4) The source of regional differences is that during the sample investigation period, the contribution rate of regional differences is the highest and shows a downward trend, indicating that regional differences are the main source of overall differences in the coupling and coordination of China's digital economy and real economy. The contribution rate within the region ranks second, with an increase of 16.9%. The contribution rate of super variable density increased by 59.4%, indicating the existence of provinces with lower coupling coordination levels within regions with higher coupling coordination, and this phenomenon is becoming increasingly severe. Based on the previous analysis, the significant difference in the coupling and coordination level between the digital economy and the real economy in the eastern and central western regions is an important factor leading to the formation of overall differences. Therefore, further measures should be taken to narrow the gap in the level of coordination between the digital economy and the real economy in the eastern and central western regions, and to address the overall spatial imbalance in the level of coordination between China's digital economy and the real economy.

3.3. Dynamic Evolution of Integration and Coordination between Digital Economy and Real Economy

To accurately depict the distribution and dynamic evolution characteristics of the coordination level of "digital real integration" in 30 provinces and three major regions of China, this paper combines the above analysis to draw a three-dimensional Gaussian kernel density map of the coupling coordination level of the national, eastern, central, and western regions from 2013 to 2022.

By analyzing the dynamic evolution characteristics of the center point position, shape, extensibility, and peak number of the distribution curve.

(1) Center point position. From 2013 to 2022, the central point of the core density of the coordination degree of "digital real integration" in 30 provinces across the country has been moving to the right year by year, indicating that the level of coupling and coordination between the digital economy and the real economy in the country is gradually improving, and the coupling and coordination situation is increasingly improving.

(2) The distribution pattern of the main peak. The main peak distribution pattern of the kernel density of the coordination degree of "digital real integration" in 30 provinces across the country from 2013 to 2022 showed a trend of height decrease and width widening, indicating that the differences in

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the coordination level of "digital real integration" among the 30 provinces across the country are continuously increasing.

(3) Distribution extensibility. The distribution and extension of the coordination degree distribution curve of the integration of data and reality in 30 provinces across China from 2013 to 2022 showed a "right tail, extension and expansion" characteristic. This indicates that the difference between provinces with higher coupling coordination levels (such as Guangdong and Beijing) and lower coupling coordination levels (such as Ningxia and Qinghai) shows an expanding trend, and the spatial imbalance trend is prominent.

(4) Polarization characteristics. From 2013 to 2022, the number of peaks in the distribution curve of the coordination degree of "digital real integration" in 30 provinces and western regions of China remained basically two, but the bimodal phenomenon was relatively mild and gradually not obvious. This indicates that there is a certain polarization phenomenon in the country and western regions, but it is not significantly accompanied by a weakening trend.

4. Conclusion

The results of this article indicate that, from an overall perspective, the level of coordinated development of "digital real integration" in 30 provinces of China is steadily increasing. This indicates that the overall development of "digital real integration" in China is improving, but the level of coupling coordination is not high, and there is still significant room for improvement; The problem of imbalanced development in the integration of data and reality at the regional and provincial levels is prominent, presenting a gradient feature of "high in the east and low in the west"; The regional differences in the level of coupling and coordination between China's digital economy and the real economy are the main factors leading to the formation of overall differences; The coupling and coordination level of digital economy and real economy in the national and western regions shows a weak polarization phenomenon, while the eastern and central regions do not show polarization phenomenon; Further measures should be taken to narrow the gap in the level of coordination between the digital economy and the real economy in the eastern and central western regions, and to address the overall spatial imbalance in the level of coordination between China's digital economy and the real economy.

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