Research on Coupling Mechanism between Digital Inclusive Finance and Scientific and Technological Innovation: Spatiotemporal Characteristics and its Driving Factors

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Abstract. Based on the coupling and coordinated development mechanism of digital inclusive finance and scientific and technological innovation, the evaluation indexes for digital inclusive finance and scientific and technological innovation are constructed respectively. Besides, the coupling and coordinated development relationship and their driving factors in 30 provinces and cities from 2011 to 2021 are studied by using the evaluation model via the entropy weight method, coupling and coordination model, and two-way fixed effect model. The results are as follows. 1) Obvious regional differences exist in the coupling coordination between digital inclusive finance and scientific and technological innovation in China, which is high in the east and the south but low in the west and the north, although such differences are decreasing year by year .2) Using the two-way fixed effect model shows that the development of foreign trade, human capital, financial support, and other factors have a high correlation with the coupling and coordinated development of digital inclusive finance and science and technology innovation system. Premised on the existing research, this paper further analyzes the coupling and coordination of digital inclusive finance and scientific and technological innovation in various provinces of China at present, including time and space dimensions, which provides practical strategic guidance for the government to promote the coordinated development of them, leaving profound lessons for improving the national science, technology, and finance.

Keywords: Entropy Weight Method; Coupling Coordination Model; Theil Index; Two-Way Fixed Effect Model.

1. Introduction

The 20th National Congress of the Communist Party of China clearly stated that science and technology are the primary productive forces, talents are the top resources, and innovation is the fundamental driving force. Up against the rapid development of new information technologies such as the Internet, blockchain, cloud computing, and artificial intelligence, we must seize opportunities for the integration of the digital economy and inclusive finance (Liu, L. H., 2023). Thus, it is necessary to research the relationship between digital inclusive finance and scientific innovation. The research on how digital inclusive finance impacts scientific and technological innovation is abundant with fruitful results. However, in-depth studies on the dynamic evolution track and characteristics of their coupling coordination are insufficient. Therefore, based on the panel data of 30 provinces in China from 2011 to 2021, this paper not only constructs a comprehensive evaluation index of digital inclusive finance and scientific and technological innovation, but also measures the coupling coordination index of digital inclusive finance and scientific and technological innovation in 30 provinces from 2011 to 2021 through entropy weight method and coupling coordination model, to reflect the spatial linkage effect of the coupling coordination of digital inclusive finance and scientific and technological innovation among provinces. At the same time, using the fixed effect model in econometrics, this paper further analyzes the possible factors affecting their coordinated development and provides suggestions for their coordinated development.

2. Research Design

2.1 Sample Introduction and Data Sources

This paper mainly studies the coupling and coordination relationship between digital inclusive finance and scientific and technological innovation, so a comprehensive evaluation index system is established from two aspects, which are digital inclusive finance and scientific and technological innovation. Digital inclusive finance mainly includes three dimensions: coverage breadth, use depth, and digitalization degree. Scientific and technological innovation includes three secondary indicators, such as innovation input, R&D output, and industrialization of R&D achievements, which are divided into several tertiary indicators. According to the measurement index system of coupling coordination degree between digital inclusive finance and scientific and technological innovation, the original data of this paper mainly comes from *2022 China Statistical Yearbook on Science and Technology*, *2022 China Statistical Yearbook*, and *Digital Inclusive Finance Index of Peking University*, which analyzed the relevant data of 30 provinces and cities in China from 2011 to 2021, with Tibet, Hong Kong, Macao, and Taiwan regions excluded due to the serious lack of data.

2.2 Research Methodology

2.2.1 Entropy Weight Method

The specific steps are as follows.

(1) Construct a judgment matrix. Assuming that m objects are evaluated with n indexes, a judgment matrix is formed and denoted as R'_{ij}, where i = 1...m and j = 1...n. To eliminate the influence of data dimension, it is necessary to process data dimensionless. After the data is non-dimensionalized, the elements in the judgment matrix are normalized to a probability distribution, so that the processed data values are between [0, 1], with the normalization formula shown as follows:

$$R_{ij} = \frac{R'_{ij} - minR'_i}{maxR'_i - minR'_i} \tag{1}$$

In the formula, R_{ij}represents the normalized data, $maxR'_i$ and $minR'_i$ represent the maximum and minimum of different objects under the same index respectively. In order to eliminate the influence of zero value when calculating information entropy, the normalized data is all plus 1 and recorded as X_{ij}.

(2) Determine the information entropy of the evaluation index. The specific calculation formula is as follows.

$$H_j = -\frac{1}{lnm}\sum_i f_{ij} ln(f_{ij}) \tag{2}$$

Where $f_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}}$, i = 1.....m, j = 1.....n denotes the index characteristic ratio. To eliminate the negative influence caused by the logarithm, negative values should be taken from the formula.

(3) Determine the weight of each index.

$$w_j = \frac{1-H_j}{\sum_{j=1}^{n}(1-H_j)} \tag{3}$$

According to the calculated weight, the commented objects can be measured: $m_j = \sum_{j=1}^{n} w_j R_{ij}$.

2.2.2 Evaluation Model of Coupling Coordination

The coupling mechanism between digital inclusive finance and scientific and technological innovation is as follows. On the one hand, digital inclusive finance can promote high-quality economic development by improving the innovation ability of enterprises, expanding technology spillovers, enhancing industrial upgrading, and raising the level of education and government governance (Chen, X. et al., 2023). On the other hand, the development of scientific and technological innovation greatly motivates the development of digital finance. Hence, the coupling theory is applicable to study their relationship, with the coupling model of the interaction between digital inclusive finance and technological innovation constructed as follows.

$$C = 2\sqrt{\frac{U_1 U_2}{(U_1+U_2)^2}} \quad (4)$$

Where C represents the coupling of the interaction between digital inclusive finance and scientific and technological innovation, reflecting the strength of their interaction and coupling. U_1 and U_2 represent digital inclusive finance and science and technology innovation index respectively. It can be seen from formula (4) that the value of C is between [0, 1]. When C=0, the coupling between digital inclusive finance and technological innovation is low in a disorderly state. When C=1, the best coupling and then the benign resonance coupling is achieved between them (Tan, Y. Z. et al., 2021). C, as an index to measure the coordination between digital inclusive finance and scientific and technological innovation in a certain region, is significant for judging their coordinated development in this region. However, there are some defects. When the digital inclusive finance and science and technology innovation index are relatively low, the calculated coupling degree may also be relatively high, and "pseudo-coupling" appears at this time. In order to overcome this defect, this paper introduces the coupling coordination degree model:

$$D = \sqrt{C \times T} \quad (5)$$

$$T = \alpha U_1 + \beta U_2 \quad (6)$$

Where D is the coupling coordination degree between digital inclusive finance and technological innovation; T is a comprehensive coordination index between digital inclusive finance and technological innovation, which is used to reflect their comprehensive development level. α and β represent the importance of their respective systems in calculating the coordination index. This paper holds that the two systems are equally important, so $\alpha = \beta = 0.5$. Given that there is no unified standard for the division of coupling coordination degree in academia, this paper draws lessons from the existing research (Dai, Z. M.et al., 2023), with the classification of coupling coordination degree shown as follows.

Table 1. Classification Standard for the Level of Coupling Coordination Degree

Coupling Coordination Degree	Coupling Coordination Level	Coupling Coordination Degree	Coupling Coordination Level
0<D<0.2	Extreme Imbalance	0.2<D<0.4	General Imbalance
0.4<D<0.5	Reluctant Coordination	0.5<D<0.6	Primary Coordination
0.6<D<0.8	Good Coordination	0.8<D<1	Excellent Coordination

2.2.3 Introduction to Index System

Digital Finance Index System, Digital Finance Research Center of Peking University, and Ant Financial Group jointly compiled China Digital Inclusive Finance Index at provincial, municipal, and county levels, which covers the data of all provinces in China from 2011 to 2021 with strong authenticity, authority, and credibility, meeting the requirements of the data required for this empirical study. Therefore, this paper only selects the provincial data reflecting the coverage breadth, use depth, and digitalization degree as the index to measure the development of regional digital inclusive finance. The specific compilation method of the index refers to the research of Guo Feng et al.

Reflecting the advantages and disadvantages of a country or enterprise in scientific and technological innovation, the index system of scientific and technological innovation provides a basis and reference for related strategy and policy making. Following the principles of being science-based, relevant, comparable, and available, this paper constructs a comprehensive evaluation index system of scientific and technological innovation mainly from three aspects, that is, innovation input, R&D output, and specialization of R&D output (Li, E. L. et al., 2018). Lessons are also further drawn from the research (Hua, J. et al., 2019) to set up eight secondary indicators, as shown in Table 2.

Table 2. Digital Inclusive Finance and Evaluation Index System of Scientific and Technological Innovation

Target	Criterion	Indicator
System of Digital Inclusive Finance	Coverage Breadth	-
	Use Depth	-
	Digitization Degree	-
System of Scientific and Technological Innovation	Innovation Investment	R&D Expenditure/GDP
		Fiscal Expenditure on Science and Technology/Fiscal Expenditure
	R&D Output	Full-Time Equivalent of RD Personnel
		Patent Application for Invention
		Invention Patent Authorization
	Industrialization of R&D	Sales Revenue of New Products of Industrial Enterprises Above Designated Size
	Results	Sales Revenue of New Products in High-Tech Industries
		Technology Market Turnover

2.2.4 Setting of Econometric Model

The possible driving factors affecting their coupling and coordination are as follows. (1) Human capital: This paper uses the average number of years of getting an education (edu) to measure the human capital of each region. (2) Foreign trade: It can be measured from the aspects of foreign trade development, the balance of development, the growth level, the development of foreign trade, development potential, etc. (Zeng, P. et al., 2022). From the perspective of foreign trade development, this paper selects the proportion of import and export trade to GDP (*tra*) as a measure index. (3) Marketization development: It is usually measured by the marketization index (*mark*), comprehensively reflecting five aspects, including the relationship between government and market, the development of a non-state-owned economy, the development of product market, the development of factor market, and the market service environment (Zhang, Z. D. et al., 2020). (4) Urbanization level: Relevant studies show that digital inclusive finance can significantly promote new urbanization (Zhang, L. et al., 2023), so this paper selects the urbanization rate (*lntown*) to reflect the urbanization level of a region. (5) Financial support: Government investment through financial funds can not only promote the R&D and application of digital inclusive finance technology, but also accelerate technological innovation and achievement transformation. Therefore, this paper chooses the ratio of fiscal expenditure to GDP (*fan*) as the measure index of fiscal expenditure. (6) Industrial structure: Referring to the variable selection of relevant research, this paper selects the proportion of tertiary value-added industry and secondary value-added industry (*lnthr*) as the measurement index of industrial structure.

The two-way fixed effect model is introduced to further analyze the driving factors of the coupling coordination between digital inclusive finance and technological innovation. Using the indicators mentioned above to measure the driving factors, the two-way fixed effect model is as follows.

$$Y_{i,t} = \beta_0 + \beta_1 tra_{i,t} + \beta_2 edu_{i,t} + \beta_3 lnthr_{i,t} + \beta_4 lntown_{i,t} + \beta_5 mark_{i,t} + \beta_6 fan_{i,t} + \mu_i + v_t + \epsilon_{i,t} \quad (7)$$

Where $Y_{i,t}$ represents the coupling coordination index of digital inclusive finance and scientific and technological innovation; *lnthr* and so on represent the logarithmic transformation of the original data. μ_i is the individual fixed effect, v_t is the time fixed effect, $\epsilon_{i,t}$ is the random error effect, and β_i (i = 1, ..., 7) is the coefficient to be concerned in this paper.

3. Empirical Results

3.1 Analysis of Spatiotemporal Characteristics of Digital Inclusive Finance and Regional Innovation

The entropy method is used to calculate the development of digital inclusive finance and scientific and technological innovation in 30 provinces in China from 2011 to 2021 (shown in Table 3). Considering its overall situation, the average value of comprehensive measurement of digital inclusive finance and scientific and technological innovation in 2011-2021 is further calculated, with the characteristic map of time series change shown in Figure 1.

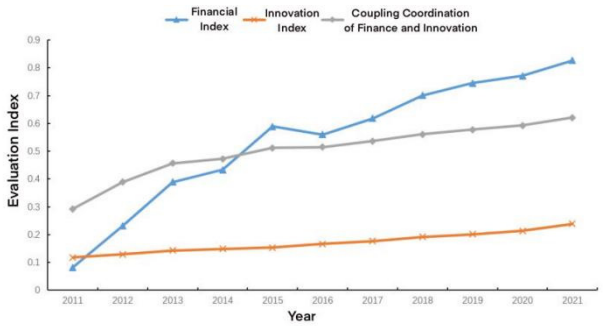

Figure 1. Comprehensive Measurement of National Digital Inclusive Finance and Science and Technology Innovation

3.1.1 Overall Trend

As shown in Figure 1, in terms of digital inclusive finance, the average value of comprehensive measurement of digital inclusive finance in 2011 was 0.081978, and the average value in 2021 was 0.8269, achieving leap-forward development. The period from 2011 to 2015 is a stage of rapid development for digital inclusive finance In terms of scientific and technological innovation, the average value of comprehensive measurement of scientific and technological innovation in 2011 was 0.1171, and the average value in 2021 was 0.2389, which shows a good development trend. From 2011 to 2021, scientific and technological innovation showed a steady upward trend.

3.2 Spatiotemporal Evolution Trend of Coupling Coordination Degree

According to the coupling coordination model, the coupling coordination degree of 30 provinces in China from 2011 to 2021 is calculated and shown in Table 3. Considering its overall trend, the average coupling coordination degree of the whole country and four major regions from 2011 to 2021 is further calculated, with the chart of time series change is shown in Figure 2.

3.2.1 Time Trends

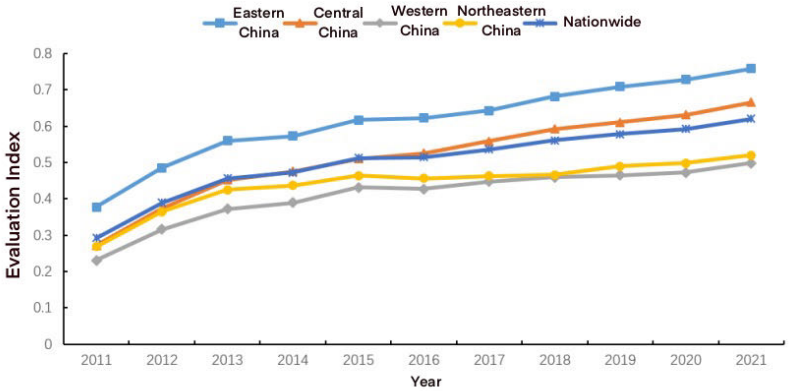

Figure 2. The Coupling Coordination Degree Between China's Digital Inclusive Finance and Technological Innovation from 2011 to 2021

As shown in Figure 2,from the perspective of time and space, the coupling and coordination relationship between Chinese inclusive finance and scientific and technological innovation has experienced four development stages, that is, general imbalance, reluctant coordination, primary coordination, and good coordination. Generally speaking, the degree of coupling coordination between digital inclusive finance and the overall system of scientific and technological innovation is on the rise from 2011 to 2021. Besides, the coordinated development of digital inclusive finance and science and technology innovation system in the eastern region is always higher than the national average, the central region is close to the national average, and the western and northeastern regions are always lower than the national average.

Table 3. Coupling Coordination Index of Digital Inclusive Finance and Scientific and Technological Innovation from 2011 to 2021

	2011	2013	2015	2017	2019	2021	Mean value
The east	0.3777	0.5602	0.6174	0.6435	0.7087	0.7588	0.6144
Middle part	0.2721	0.4519	0.5100	0.5587	0.6113	0.6658	0.5153
west	0.2312	0.3725	0.4314	0.4480	0.4650	0.4987	0.4102
northeast	0.2692	0.4256	0.4639	0.4629	0.4900	0.5207	0.4414

3.2.2 Spatial Evolution Trend

From the regional perspective based on Table 3, the coupling coordination between digital inclusive finance and scientific and technological innovation in China is characterized by “strong in eastern China and weak in western China, high in southern China and low in northern China”. Although the coupling coordination has greatly increased after rapid development in the western and northeastern regions, the above-mentioned trend has not changed. The coupling coordination degree between digital inclusive finance and scientific and technological innovation in China shows an obvious polarization balance.

3.2.3 Variance Analysis

To better explore the regional differences in the development of coupling coordination between digital inclusive finance and scientific and technological innovation in China, the calculated coupling coordination index is brought into the calculation formula of the *Theil* index, which obtained the *Theil* index from 2011 to 2021. Besides, the proportion of the average value of coupling coordination in the four regions from 2011 to 2021 and the column-line combination diagram of the *Theil* index are shown in Figure 3.

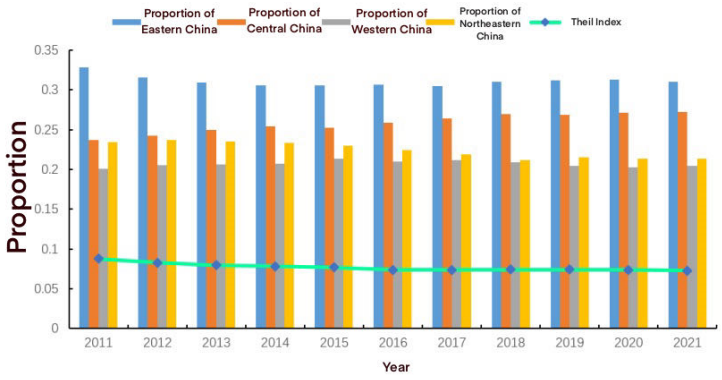

Figure 3. Proportion of the Average Value of Coupling Coordination and *Theil* Index of the Four Major Regions From 2011 to 2021

As shown in Figure 3, although the digital inclusive finance and technological innovation in the four major regions are promoting each other from 2011 to 2021, central regions have the greatest development with the best coordination. On the whole, the *Theil* index decreased from 0.0874 in 2011

to 0.0727 in 2021 with a subtle decline. It is also shown that although the regional differences in coupling coordination between digital inclusive finance and scientific and technological innovation are slowly decreasing from 2011 to 2021, the development of the eastern regions is always the best by virtue of its geographical and resource advantages with relatively large regional differences.

3.3 Analysis of Influencing Factors

Using Stata software, this paper not only studies the relationship between the coupling coordination of digital inclusive finance and science and technology innovation system, average years of getting an education (*edu*), the ratio of import and export trade to GDP (*tra*), marketization index (*mark*), urbanization rate (*lntown*), the ratio of fiscal expenditure to GDP (*fan*), and the ratio of the tertiary value-added industry to secondary value-added industry (*lnthr*) as shown in Table 4.

Table 4. Estimation Results of Two-Way Fixed Model

y	Coef.	Std.Err.	t	P>|t|
tra	0.1962*	0.0958	2.0500	0.0500
edu	0.0205**	0.0090	2.2600	0.0310
lnthr	0.0349	0.0640	0.5400	0.5900
fan	0.3054***	0.0227	13.4500	0.0000
lntown	-0 1089	0 2631	-0 4100	0 6820
mark	-0.0024	0.0149	-0.1600	0.8740
R^2		0.4583		
Sample Size		330		

As shown in the results of the table, the ratio of import and export trade to GDP (*tra*) has a significant positive impact on coupling and coordinating digital inclusive finance and technological innovation, which indicates that good foreign trade development is conducive to the coupling and coordinating development of innovation infrastructure and innovation output.

The influence of average years of getting an education (*edu*) on the coupling coordination between digital inclusive finance and technological innovation has passed the significance test at 5% with a positive direction, which indicates that the higher the education, the better the coupling coordination of the system.

The influence of the proportion of tertiary value-added industry and secondary value-added industry (*lnthr*) on the coupling coordination of digital inclusive finance and technological innovation failed to pass the significance test. The industrial structure mainly involves the proportion and structure of different industries, which is not directly related to the application and development of digital inclusive finance and technological innovation.

The influence of the ratio of fiscal expenditure to GDP (*fan*) on the coupling coordination between digital inclusive finance and technological innovation has passed the significance test of 1% with a positive direction and a relatively large coefficient value, manifesting that financial support is closely related to the coupling coordination between digital inclusive finance and innovation.

4. Conclusion and Recommendations

4.1 Conclusion

(1) The overall development trend of digital inclusive finance and scientific and technological innovation in China from 2011 to 2021 is on the rise, with an imbalance that is “strong in eastern China and weak in western China”. (2) The coupling coordination of digital inclusive finance and science and technology innovation system in China is on the rise as a whole, which is obviously characterized by the phenomenon that is “strong in eastern China and weak in western China, high in southern China and low in northern China”. Meanwhile, the overall regional differences show a

narrowing trend. (4) Foreign trade development, human capital, financial support, and other factors can significantly affect the coupling and coordinating development of digital inclusive finance and scientific and technological innovation in China.

4.2 Recommendations

(1) The regional development of digital inclusive finance should be improved to promote regional innovation during the digital transformation. Thus, the government and enterprises need to formulate a clear digital transformation strategy, including the goal, feasibility analysis, priority, timetable, and financial plan of digital transformation.

(2) We should improve the construction of digital financial infrastructure, further promote the deep integration of digital inclusive finance and technological innovation, and broaden the coverage of digital inclusive finance. The government should constantly promote digital inclusive finance to give full play to its inclusive advantages. In addition, the market needs to strengthen competition, innovate continuously, and promote the upgrading and optimization of the industry.

(3) The cooperation between eastern and western regions in digital inclusive finance and scientific and technological innovation should be strengthened to promote the integration of technological innovation and digital inclusive finance development. Based on the actual situation, apart from tapping its economic development advantages and vigorously promoting digital inclusive finance services, eastern regions need to strengthen economic ties among different regions and strengthen cooperation in enterprise docking, investment cooperation, and talent exchange between the central and western regions.

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