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Article

Measurement and Empirical Research of Digital Financial Development Level

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Abstract: The digital economy has become an important driving force for high-quality economic development, and digital finance, as a key carrier for the integration of the digital economy and modern finance, has significant research value in terms of measurement analysis and theoretical mechanism exploration. To explore the development trend and regional differences of digital finance in China, this study selects 15 provinces and cities in eastern, central, and western China as research objects. Based on panel data from 2014 to 2024, it constructs an indicator system covering digital financial services (DFS), digital financial technology (DFT), digital financial environment (DFE), and digital finance application depth (DFAD). Using the entropy weight method, coupling coordination model, and grey relational model, it analyzes the development level of digital finance in China, the development status of different regions, the degree of coordinated development of various subsystems, and the core driving factors. The study found that: 1) China's digital finance development level is generally on a continuous upward trend, with the eastern region showing a significant advantage; 2) All four subsystems maintain a continuous growing trend, but their contributions differ significantly, with digital financial services (DFS) being the core driving force and the digital financial environment (DFE) being the main weakness; 3) The coupling and coordination of various indicators has gradually improved from severe imbalance to excellent coordination, with the development trends in the east, central, and western regions being consistent, but the pace of progress differing slightly; 4) Indicators with high contribution rates to development exhibit a development pattern of " policy environment - technological innovation - service scenarios" and this pattern shows heterogeneity in different regions. Based on this, the future development of digital finance in China should focus more on system synergy and structural optimization, taking the improvement of the digital financial environment (DFE) as a breakthrough to promote the integration of digital financial technology innovation and service scenarios, thereby enabling digital finance to better serve the real economy and help achieve high-quality economic development.

Keywords: Digital finance; Entropy weight method; Coupling and coordination; Grey relational degree; Regional differentiation

1. Introduction

Digital finance deeply integrates digital technology and financial functions, focusing on high-tech such as big data, cloud computing, blockchain, and artificial intelligence. Compared with traditional finance, it has significant advantages such as low cost, high efficiency, wide coverage, and dynamism. With the deepening of globalization and technological innovation, digital finance has become an important force in promoting the transformation of the financial system and assisting the digital transformation of industries, profoundly affecting the quality and efficiency of economic and social development. At present, China's digital finance development has entered a new stage. In November 2024, the People's Bank of China, the National Development and Reform Commission, the Ministry of Industry and Information Technology, the State Administration for Financial Supervision, the China Securities Regulatory Commission, the National Data Administration, and the State Administration of Foreign Exchange jointly issued the "Action Plan for Promoting the High-Quality Development of Digital Finance", emphasizing the need to accelerate the digital transformation of the financial industry

and take “ forming a good situation of coordinated development of digital finance, science and technology finance, green finance, inclusive finance, and pension finance “ as the key construction direction of the financial field in the later stage [1]. As an important integration of digital economy and traditional finance, digital finance is of great significance to serving the real economy. Therefore, in-depth discussion of its development level and influencing factors can help us recognize the current shortcomings and potential of digital finance development and promote the financial system to better serve the high-quality development of the economy.

Having clarified the historical context and strategic significance of high-quality development of digital finance, the academic community has already launched multi-dimensional research and exploration around it. In terms of economic development, Sun Jie and Pei Ping (2025) pointed out that digital finance has five major characteristics: inclusiveness, innovation, efficiency, security and sustainability. It is of great significance to promote the efficiency of economic development and the reform of the financial system. However, it is currently facing difficulties in infrastructure construction, technology application and financial literacy. It is also necessary to strengthen the construction of digital finance regulatory system [2]. Yi Qiuping (2025) and others demonstrated that digital finance promotes the integration of digital economy and real economy by alleviating financing constraints. Moreover, the promotion effect varies depending on the development level of the region where the enterprise is located and the enterprise's willingness of digital transformation. It has a more significant impact on the eastern region with a higher level of economic development [3]. Yuihui, D. and Zhang, L. (2022) noted that the development of regional digital finance has a significant inhibitory effect on corporate financial risk, and its impact varies in terms of enterprise size, ownership nature and manager characteristics. There is a more significant effect on small and medium-sized enterprises, private enterprises and enterprises whose managers are not overconfident [4]. In terms of environment, Chunkai Zhao (2023) et al. suggested that digital finance can significantly promote Chinese residents to choose shared bicycles for travel, which is environmentally friendly. Its role is mainly reflected in three aspects: improving payment convenience, providing credit services to a wider range of residents, and improving the level of social interaction. This positive impact is also effective for vulnerable groups, demonstrating the inclusiveness of China's digital finance development [5]. Lu Yang et al. (2022) identified a non-linear threshold characteristic between digital inclusive finance and $PM_{2.5}$ concentration in China. Regionally, digital inclusive finance shows no significant effect in eastern China, but is significantly positively associated with $PM_{2.5}$ concentrations in central and western regions. In terms of digitalization levels, digital inclusive finance correlated positively with $PM_{2.5}$ under low digitalization, yet this relationship reverses at high digitalization levels. This indicates that the development of digital inclusive finance can improve economic efficiency and offset the environmental pressure brought by energy consumption [6]. In terms of society, Qi Wei and Sui Yiying (2025) pointed out that digital inclusive finance promotes high-quality agricultural development by providing financial support, narrowing the gap between urban and rural financial services and promoting the use of environmentally friendly agricultural technologies. This promoting effect increases with the improvement of the education level of rural residents and shows obvious differences in regions and time [7]. Liu Xianjuan (2025) found that digital inclusive finance exerts a positive empowering effect on rural revitalization, exhibiting both spatial spillover effect and non-linear increasing double-threshold characteristics. On one hand, digital inclusive finance overcomes the geographic constraints of traditional financial services through fintech, enabling more efficient liquidity and financial resource allocation; on the other hand, it fosters the development of new rural collective economies by offering financing support and reducing transaction costs [8]. In terms of technology, Tao Kong (2022) et al. documented that digital finance significantly promotes green innovation among enterprises, based on an analysis of China’s A-share listed firms over the 2011-2019 period. First, digital finance mitigates information asymmetry by addressing moral hazards and financial risks, thereby directly fostering corporate technological innovation. Besides, it enhances the quality of environmental information disclosure and eases financial constraints, which indirectly supports green innovation [9]. Ya Zhou (2022) pointed out that the digital economy has effectively removed the financing constraints of technological innovation enterprises and made up for the shortcomings of traditional finance. The study also stated that the application of digital financial technology faces challenges including information security and regulatory lag. In the future, the information advantages of new digital technologies should be fully utilized to promote the green and intelligent upgrading of digital economy [10].

2. Literature Review

2.1. Research Trends in Digital Finance

This study uses Citespace 6.4R1 software to conduct a visual analysis of literature related to digital finance measurement. The data comes from the Web of Science Core Data Collection, with the search keyword being "Digital Finance," the search timeframe being 2014-2024, and the research scope limited to finance, economics, management and so on. The document type is limited to "Article," ultimately retrieving 517 high-quality documents closely related to the research topic. Based on this, the time trend tracking function of Citespace software is used to conduct a visual analysis of existing research results. It traces the changes in research hotspots in digital finance measurement at different stages, thereby revealing current research trends and potential future development directions.

By visualizing the co-occurrence frequency and clustering of keywords in relevant literature in the field of digital finance research, it can be intuitively found that the literature on digital finance research from 2014 to 2024 is mainly clustered into 7 dimensions. Among them, the top 4 clusters are Digital Transformation (#0), Carbon Emissions (#1), Digital Inclusive Finance (#2), and Digital Economy (#3) (Figure 1). The prominence of these clusters is mainly due to the progress of information technology, the promotion of global dual-carbon targets and the needs of regional development. For the Digital Transformation (#0) cluster, its high ranking mainly stems from the rapid development and iteration of information technology. In particular, advances in digital infrastructure including cloud computing and big data have enabled technological upgrading in financial institutions. At the same time, surging demand for digitalization across enterprise supply and industrial chains has made digital finance service efficiency highly dependent on the depth and quality of digital transformation, thereby positioning digital transformation as a core research focus [11]; Withinn the Carbon Emissions (#1) cluster, under the promotion of global dual carbon targets, green credit, green funds and similar instruments have become critical to capital guidance. The efficient and transparent operation of carbon market's relies on digital technology, while firms' financing needs for green R&D and low-carbon transition require affordable financial support, all of which brings carbon emissions a central research topic (Hui Zhao et al., 2021) [12]; In addition, Digital Inclusive Finance (#2) has significantly reduced the cost of financial services, enabling small enterprises and rural areas that are not accessible by the traditional financial system to obtain financing opportunities. Meanwhile, it shows significant value in promoting entrepreneurship and employment. However, there's also new challenges like digital discrimination and platform monopoly, which further arouses the attention of the academic community, making it a research hot spot in the field of digital finance (Wang W et al., 2023) [13]. Digital economy provides new scenarios and technical support for various financial activities, making Digital Economy (#3) an indispensable theoretical foundation for digital finance research. The government has also introduced digital finance-related policies to strengthen financial supervision, data security, inclusive development, etc., and promote the orderly operation of the digital finance system, while social demand for convenient and efficient financial services is constantly growing. The combined effect of policy and market demand further solidifies the core position of the aforementioned major themes. Academic research focusing on these key dimensions has emerged as a core academic concern, and thus provide important support for understanding the logic of future social development.

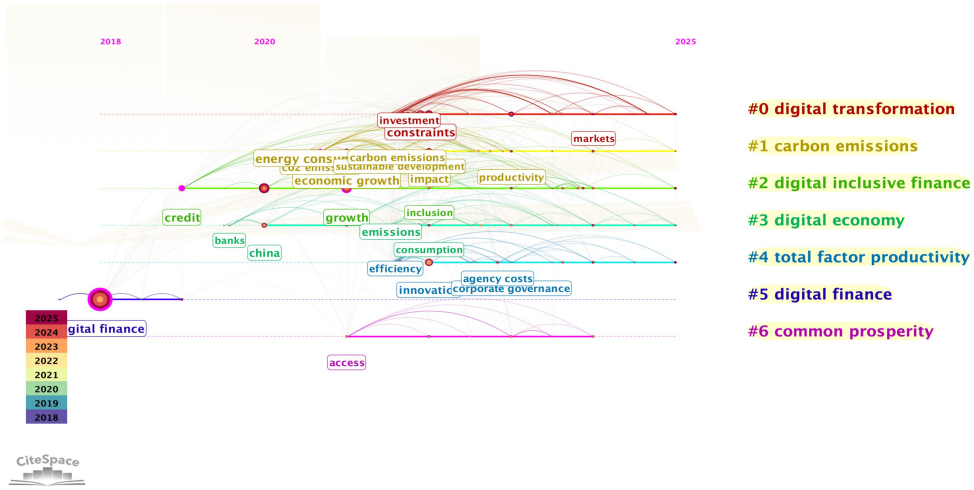


Figure 1. Analysis of the Co-occurrence Time Trend of Digital Finance Keywords

A temporal trend analysis of keyword clustering reveals a shift in research concentration from 2016 to 2025: from Digital Finance (#5) itself, to Digital Inclusive Finance (#2) and Digital Economy (#3), to

Total Factor Productivity (#4) and Carbon Emissions (#1), and finally to Digital Transformation (#0) and Common Prosperity (#6) (Figure 1). Analysis of sub-stages reveals: 1) Before 2018, digital finance was in its initial exploratory stage. During this period, academic attention focused on clarifying its connotation and operational model. In Figure 1, Digital Finance (#5) is presented as an independent node, not yet closely connected with other fields. 2) From 2018 to 2020, research dimensions rapidly expanded, combining with economic and social issues. The emergence of keywords such as Economic Growth and Poverty indicates that Digital Inclusive Finance (#2) has become the central theme. As digital finance covers the lower-tier market, its empowering role in economic growth and poverty reduction has been the focus of academic attention. With digital economy policies being introduced intensively during this period, the connection between Digital Economy (#3) and digital finance was strengthened, and digital finance was incorporated into the overall framework of digital economy. The trend of integration of digital economy and real economy began to emerge [14]. 3) From 2021 to 2023, research focus shifted to efficiency, sustainability and innovation. Keywords such as Total Factor Productivity (#4) and Carbon Emissions (#1) became the core of research. During this period, financial market was driven by rapid development of science and technology and academic community has begun to evaluate the actual improvement effect of digital finance on economic efficiency [15]. The co-occurrence of Sustainable Energy, Green Finance and other terms reflects that digital finance has been endowed with the function of promoting green and sustainable transformation [16]. Terms like Technological Innovation reflect the research heat of digital financial technology development. 4) In 2024-2025, Digital Transformation (#0) and Common Prosperity (#6) became core research themes. Studies in this period centered on the high-quality development of the economy and society enabled by digital finance. The growing attention to Digital Transformation (#0) reflects its identified role in remedying traditional financial deficiencies and supporting real economy's digital upgrade. The integration of Common Prosperity (#6) into digital finance research signals a shift toward exploring its contributions to social welfare and sustainable balanced economic and social development.

2.2. Research Methods in Digital Finance

Research in digital finance not only continues the classic methods of traditional financial analysis, but also exhibits a trend of multidisciplinary development. Currently, different scholars have chosen diverse methodologies and tools based on their research topics and data selections.

In the application of traditional financial methods, econometric methods remain an important tool for empirical research in digital finance. Yi Xingjian and Zhou Li (2018) used a panel fixed effects model to analyze the impact of digital inclusive finance on residents' consumption, revealing the role of digital inclusive finance in alleviating liquidity constraints, facilitating payments, and promoting consumption [17]. Huang Qian, Li Zheng, and Xiong Deping (2019) used a two-way fixed effects model (LSDV method) to analyze the overall impact of digital inclusive finance on poverty alleviation, the characteristics of group heterogeneity, and the transmission mechanism [18]. Guo Feng et al. (2020) employed the convergence test α and the Moran index within spatial econometric framework to systematically analyze the regional convergence, spatial clustering, and heterogeneity of China's digital inclusive finance from 2011 to 2018, and depicted its developmental trends across regions [19]. Nie Xiuhua et al. (2021) used the two-step system GMM estimation method concerning dynamic inertia and endogeneity of technological innovation, and analyzed the impact of the digital finance application depth and the degree of digitalization on the level of regional technological innovation [20]. Tian Gezi and Zhang Xun (2022) adopted the difference-in-differences (DID) method to analyze how digital economic development affects non-agricultural employment, and verified the labor division effect of digital economy in promoting labor transformation [21]. He Guosheng and Yan Jiani (2023) used the spatial Durbin model (SDM) and stepwise regression method to verify the impact of digital finance on urban economic resilience, and investigate its underlying mechanisms in enhancing entrepreneurial activity and narrowing the urban-rural income gap [22]. Qian Li et al. (2024) used the panel threshold model to systematically tested the nonlinear relationship between digital inclusive finance and agricultural net carbon sink efficiency in different intervals, providing empirical support for digital finance's capacity to empower low-carbon development of agriculture [23].

In addition to quantitative analysis, qualitative research and case studies have also played an important role in digital finance research. Zhang Yuanyuan et al. (2025) used dynamic qualitative comparative analysis (QCA) to explore the synergistic effect of digital technology, organization and environmental factors, and summarized the differentiated paths for the improvement of new quality productivity in the two regions [24]. Li Yan et al. (2025) used fuzzy set qualitative comparative analysis (fsQCA) to conduct configuration analysis on relevant data from 30 provinces in China when studying how digital finance empowers high-quality agricultural development [25]. Luo Hehua et al. (2023)

conducted a field survey of 1,022 farmers in Hebei, Hunan and Guangxi provinces to obtain micro data on their digital finance usage and household consumption. They further examined the mediating role of household income in the relationship between digital finance and farmers' consumption [26]. Huang Junxin (2023) took nine cities in the Pearl River Delta urban agglomeration as case studies to identify how digital finance affects e-commerce development. He analyzed the spatiotemporal characteristics of e-commerce in the case cities and summarized multi-dimensional pathways through which digital finance promotes the coordinated development of regional e-commerce [27].

With the deep integration of financial activities and digital technologies, research methods in the field of digital finance have both continued the traditional financial analysis framework and been continuously enriched by big data-driven and multidisciplinary integration. On the one hand, econometric methods remain an important tool for studying the impact mechanisms and effectiveness of digital finance. Scholars have effectively tested issues such as endogeneity and heterogeneity through methods including fixed-effects models, spatial econometric models, system GMMs, and panel threshold regression. On the other hand, the application of qualitative comparative analysis, fuzzy set configuration analysis, and case studies has led to a research trend of interdisciplinary integration and multi-dimensional measurement. Based on the above development of research methods, this study will take a regional perspective, starting from the macro-meso-micro logic, and adopt the "entropy weight-coupling coordination-grey relational degree" model. It will use the entropy weight method for weighted measurement and comprehensive comparison, explore the correlation between the development of different subsystems through coupling coordination model, and reveal the intensity of the effects of various influencing factors through grey relational degree model, aiming to present a more comprehensive and in-depth view of the level and driving factors of digital finance development in different regions.

2.3. Measurement Indicators in Digial Finance

In the field of traditional financial research, academics and international organizations usually construct indicator systems from two dimensions: access and usage. Typical indicators include access channel density, account ownership rate, savings and lending rate, insurance penetration rate and payment transaction volume [28-29]. The traditional financial indicator system provides a basic assessment tool for global inclusive finance field. However, with the integration of modern information technology and the diversification of financial participants, the emergence of digital finance has changed the connotation of traditional indicators, and the traditional indicator system has gradually merged with the digital dimension. At present, in the research on digital finance measurement in China, the "Peking University Digital Inclusive Finance Index" compiled by the Digital Finance Research Center of Peking University (in cooperation with Ant Group Research Institute) is widely cited and is one of the core reference indicators for domestic research. The indicator system includes three primary dimensions: coverage breadth, usage depth and digitalization degree, as well as 33 specific indicators [30]. In addition to the Peking University Index, scholars are also trying to construct different indicator systems. When studying the development of digital finance in Chinese cities, Gaoke Liao et al. (2022) constructed an urban financial indicator system, which covers three dimensions: Digital Financial Services, Digital Finance Technology and Digital Financial Environment [31]. The World Bank's Global Findex Database, released in 2025, is a demand-side financial inclusion indicator system, and includes 131 indicators in six dimensions: accounts, savings, borrowing, emergency funds, remittances and payments [32].

Based on current research trends and drawing on existing research methods, this study integrates the indicator system of Gaoke Liao and the Digital Inclusive Finance Index of Peking University to construct an indicator system for measuring the development level of digital finance. Specifically, it covers four subsystems: Digital Finance Services (DFS), Digital Finance Technology (DFT), Digital Finance Environment (DFE), and Digital Finance Application Depth (DFAD). Under each subsystem, a secondary indicator system is constructed.

2.4. Summary

Current research in the field of digital finance has yielded abundant results. Research hot spots have gradually expanded from conceptual framework to topics including digital inclusive finance, digital economy, and digital transformation, with a greater focus on economic and social development. Research methods continue to utilize traditional econometric methods such as spatial econometric models and fixed-effects models, while also exhibit a trend of multidisciplinary integration. Indicator systems such as the Peking University Digital Inclusive Finance Index and the World Bank Global Findex provide multi-dimensional perspectives for measuring digital finance. However, existing research still has shortcomings. Firstly, comparative studies on regional level often focus on single dimensions such as regional heterogeneity and spatial spillover effects, lacking a systematic comparison of digital finance

development level of different regions in China. Secondly, the analysis of the synergistic relationship between digital finance and regional development is not in-depth enough, making it difficult to analyze the impact of policies and reveal the inherent differences in the development of digital finance in different regions. Thirdly, existing measurement methods are mostly limited to verifying the effects of single mechanisms, lacking integrated research that combines different influencing factors.

Accordingly, this study selects five representative provinces and cities from eastern, central and western China respectively, taking these 15 provinces and cities as research objects. Using the research method of "entropy weight method-coupling coordination model-grey relational degree model", this study will comprehensively analyze the differences, synergistic characteristics and core influencing factors of digital finance development across regions, aiming to provide support for the formulation of region-specific digital finance development policies.

3. Research subjects, methods, and design

3.1. Research Subjects

This study selects Beijing, Shandong, Shanghai, Zhejiang, and Guangdong in eastern China; Anhui, Jiangxi, Henan, Hubei, and Hunan in central China; and Shaanxi, Chongqing, Sichuan, Yunnan, and Qinghai in western China as research objects (Figure 2). Through a cross-regional comparative analysis of eastern, central, and western region, it measures the development level of digital finance and influencing factors in different areas of China. Firstly, these provinces (municipalities) are important development areas in China's three major economic blocs. They are representative in terms of geographical location and topography, comprehensively covering the digital finance development scenarios in major regions of China. Secondly, to eliminate the interference of excessive differences in economic size leading to an imbalance in the foundation of digital finance development, the provinces (municipalities) selected have similar GDP scales in recent years, providing a comparable economic foundation. Finally, these provinces (municipalities) are all pilot or pioneering areas for China's national strategies related to digital finance, and their development models and policy orientations have regional radiating significance.

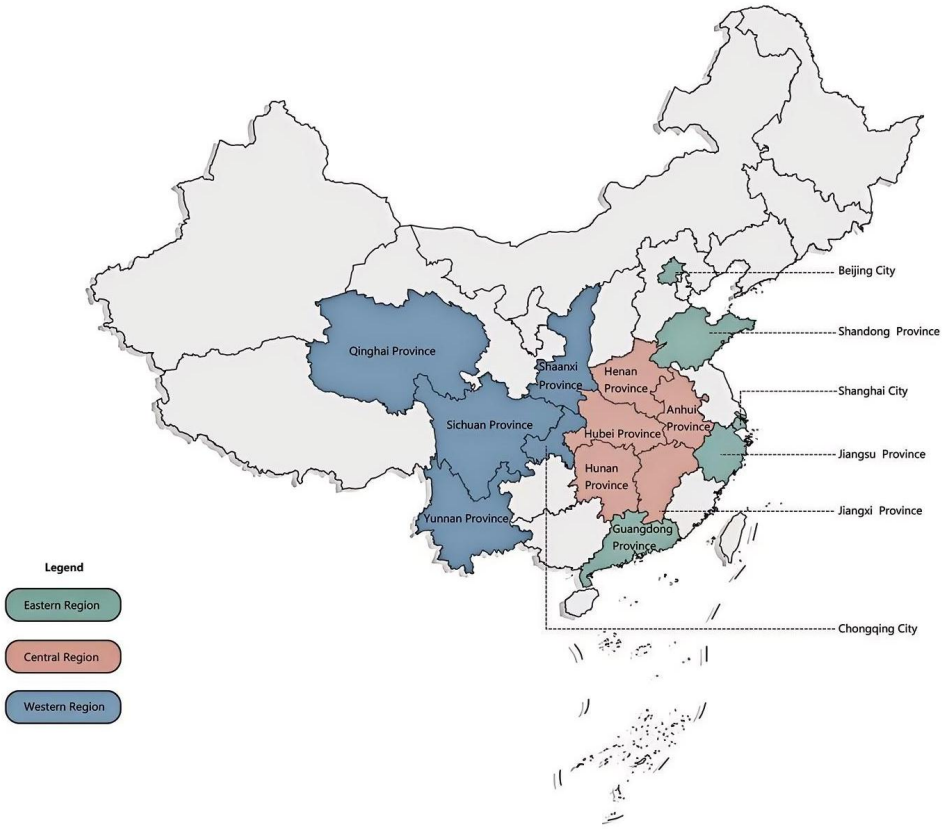


Figure 2. Distribution of Provinces (Municipalities) Selected for Digital Finance Measurement

3.2. Research Methods

3.2.1. Location Entropy Weigh Method

Entropy weighting is an objective weighting method based on information entropy theory. It determines the weight by quantifying the information uncertainty of evaluation indicators. It is often used for multi-dimensional comprehensive evaluation and can effectively avoid subjective weighting bias and improve the credibility of evaluation results. Its principle is that the greater the degree of variation of indicator data, the smaller the information entropy, the richer the amount of effective information contained, and the higher the corresponding weight; conversely, the lower the weight [33-36].

Firstly, to address the differences in the dimensions of digital finance evaluation indicators, the raw data is standardized:

$$Y_{ij} = \frac{X_{ij} - X_{j\min}}{X_{j\max} - X_{j\min}} \left(Positive\ indicator \right) \ or\ Y_{ij} = \frac{X_{j\max} - X_{ij}}{X_{j\max} - X_{j\min}} \left(Negative\ indicator \right) \quad (1)$$

In the formula, X_{ij} is the original value of j (the indicator) of i (the research object); $X_{j\min}$ and $X_{j\max}$ are the minimum and maximum values of j among all research objects, respectively; Y_{ij} is the standardized indicator value, with a value range of [0,1].

Secondly, data shifting was performed, with a shift amount of 0.0001 added to all data. Then, based on the standardized data, the proportion of the value of i under j to the total value of that indicator is calculated:

$$P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}} \quad (2)$$

In the formula, n is the number of research subjects; P_{ij} is the proportion of i under j, reflecting the relative performance of the unit on that indicator.

Thirdly, calculate the information entropy of j based on its proportion:

$$e_j = -k \sum_{i=1}^{n} P_{ij} \ln P_{ij} \quad (3)$$

In the formula, $k = 1/\ln n$ (a constant to ensure that the entropy value is in the range of [0,1]); e_j is the information entropy of j. A smaller e_j value indicates greater difference across research units, and signifies that the indicator contributes more significantly to assess the information content of digital finance development levels.

The difference coefficients of the indicators are calculated using information entropy, and then the weights of each digital financial indicator are determined:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{m} \left(1 - e_j\right)} \quad (4)$$

In the formula, m is the total number of digital finance evaluation indicators; $1 - e_j$ is the difference coefficient of j; w_j is the weight of j, which satisfies that $\sum_{j=1}^{m} w_j = 1$. The larger the weight, the higher the influence of the indicator on the development level of digital finance. Finally, the overall score is calculated:

$$S_i = \sum_{i=1}^{n} w_j \times Y_{ij} \quad (5)$$

where S_i is the comprehensive score of i, w_j is the entropy weight of j, Y_{ij} is the standardized value of j of i.

3.2.2. Coupling Coordination Model

Coupling coordination model is a classic tool for evaluating the interaction and correlation between

multiple systems. By calculating two indicators, coupling degree and coordination degree, its quantify the strength of interaction between systems and the quality of their coordination [37-42]. Its core is to quantify the dynamic intensity of mutual dependence and constraint between systems. The more frequent and significant the interaction between systems, the higher the coupling degree, and vice versa:

$$C = \sqrt{\frac{n \cdot \prod_{i=1}^{n} \mu_i}{\left(\sum_{i=1}^{n} \mu_i\right)^n}} \tag{6}$$

In the formula, $\mu_1, \mu_2, \ldots, \mu_n$ represent the comprehensive development level of each subsystem; the value of C ranges from [0,1]. The closer C is to 1, the closer the interaction between subsystems is; the closer C is to 0, the weaker the interaction between subsystems is.

Coordination degree, based on coupling relationship, further measures the quality of benign interaction between systems, and its value directly reflects the quality of overall system coordination:

$$T = \sum_{i=1}^{n} \alpha_i \times \mu_i \tag{7}$$

In the formula, $\alpha_1, \alpha_2, \ldots, \alpha_n$ are the weights of the subsystem, which satisfy the conditions $\sum_{i=1}^{n} \alpha_i = 1$; the value range of T is [0,1]. The closer T is to 1, the higher the overall development level of the subsystem; the closer T is to 0, the lower the overall development level of the subsystem.

Coupling coordination degree is a comprehensive reflection of coupling degree and coordination degree, ultimately reflecting the tightness of interaction between systems and the degree of synergy:

$$D = \sqrt{C \times T} \tag{8}$$

In the formula, the value of D ranges from [0,1]. A larger D indicates closer interaction and a higher overall development level between systems, resulting in better coordination quality; conversely, a smaller D indicates poorer coordination quality between systems. To clarify the practical significance of coupling coordination degree, and considering the characteristics of the research object, coupling coordination degree is divided into 10 levels (Table 1).

Table 1. Classification of Coupling Coordination Levels

Coupling Coordination Value Range	Coupling Coordination Level	Coupling Coordination Value Range	Coupling Coordination Level
[0,0.1)	Extreme Disorder	[0.5,0.6)	Barely Coordination
[0.1,0.2)	Severe Disorder	[0.6,0.7)	Primary Coordination
[0.2,0.3)	Moderate Disorder	[0.7,0.8)	Intermediate Coordination
[0.3,0.4)	Mild Disorder	[0.8,0.9)	Good Coordination
[0.4,0.5)	On the Verge of Disorder	[0.9,1.0]	Quality Coordination

3.2.3. Grey Relational Model

Grey relational model analyzes the changing trends of various factors, quantifies the correlation strength between factors, and then reveals the internal structure and development trend of the system. In this study, although the coupling coordination model can measure the coordination level of various subsystems, it cannot specifically measure the correlation between the sub-indicators within each subsystem. Therefore, the grey relational model is introduced to identify the core indicators that play a key role in the development of digital finance [43-45].

Firstly, the analysis data is defined into reference sequence and comparison sequences. To eliminate dimensional differences of the indicators, data are standardized using the mean method:

$$X'_i(k) = \frac{X_i(k)}{X_i} \tag{9}$$

In the formula, $X'_i(k)$ is the standardized value of the i (the sequence) in the k (the year), $\bar{X}_i = \frac{1}{n}\sum_{k=1}^{n} X_i(k)$ is the mean of the i.

Secondly, measure the absolute difference between reference sequence and comparison sequence:

$$\Delta_i(k) = \left| X'_0(k) - X'_i(k) \right| \tag{10}$$

where $X'_0(k)$ is the standardized value of the parent sequence and $X'_i(k)$ is the standardized value of the i.

Finally, the correlation degree is calculated, which comprehensively reflects the overall correlation level between the reference sequence and the comparison sequence. The formula is as follows:

$$\delta_i(k) = \frac{\min \Delta_i(k) + \rho \cdot \max \Delta_i(k)}{\Delta_i(k) + \rho \cdot \max \Delta_i(k)} \tag{11}$$

In the formula, $\delta_i(k)$ is the correlation coefficient between reference sequence and comparison sequence; $\Delta_i(k)$ is the difference between reference sequence and comparison sequence; $\min \Delta_i(k)$ and $\max \Delta_i(k)$ are the minimum and maximum values of the difference, respectively; ρ is the resolution coefficient, which takes values in the range [0,1], and is usually taken as 0.5.

3.3. Data Sources

The data in this study primarily comes from authoritative official sources released by provincial and municipal governments, including the Statistical Yearbook (2014-2024) and the Statistical Communiqués on National Economic and Social Development of Provinces and Municipalities (2014-2024). It is supplemented by data on sub-indicators related to digital finance from the National Bureau of Statistics database and the annual reports of regional branches of the People's Bank of China. To address the issue of missing data for certain indicators in some years, a simple linear regression method is used (Table 2).

Table 2. Explanation of Indicator Variables and Data Sources

Variable Name	Calculation Method	Data Sources
Digital payment transaction volume	Annual transaction volume of digital payment business	People's Bank of China-Payment System Situation, China National Clearing Center-Statistical Data
Digital lending transaction volume	Annual transaction volume of digital lending business	People's Bank of China-Financial Statistics Report, National Bureau of Statistics-National Data
Digital insurance transaction volume	Annual transaction volume of digital insurance business	State Financial Supervision and Administration Bureau-Insurance Statistics
Number of Fintech Companies	Number of legal entities in fintech sector	State Administration for Market Regulation-Enterprise Registration Data, National Bureau of Statistics-Statistical Yearbook
Intensity of investment in scientific and technological R&D	The ratio of the sum of fiscal science and technology expenditures on digital finance and R&D expenditures of fintech companies to GDP.	Ministry of Finance-Public Disclosure of Fiscal Data; National Bureau of Statistics-National Data (GDP)
Number of patents granted	Annual number of patents granted in the digital finance field	State Intellectual Property Office -Statistics
Internet penetration rate	The ratio of broadband internet users to the region's permanent resident population	National Bureau of Statistics-Statistical Communiqué, CNNIC-Internet Development Report
Digital finance policy support intensity	Number of digital finance-related policy documents released annually	China Government Website-Policy Document Repository, Peking University Legal Database-Legal Retrieval Platform
Urban lighting index	Urban light image data	NOAA-Nighttime Light Data Download, Google Earth Engine-Nighttime Light Dataset
Core digital business usage frequency per user	The sum of the average annual number of transactions per person in digital payments, digital lending, digital insurance, and digital wealth management, divided by four.	People's Bank of China-Payment System Data
Business conversion efficiency	The ratio of actual active users of digital finance to the number of users covered by digital financial services	National Bureau of Statistics-National Data
Inclusive service coverage density	The ratio of the sum of offline inclusive finance touch-points and the number of users covered by online service portals to the resident population.	National Bureau of Statistics-Population Statistics, National Data Administration-Digital China Report

3.4. Research Design

Figure 3 shows the Research Design Diagram.

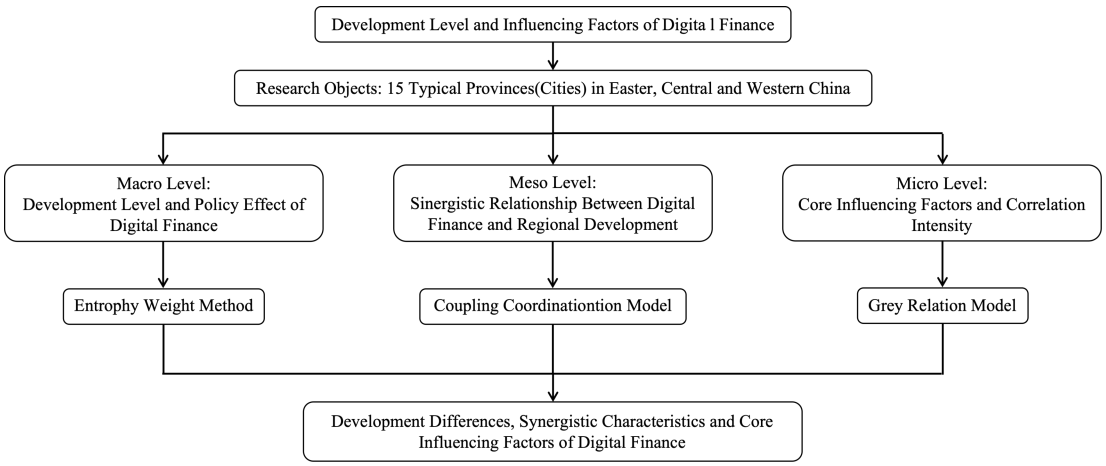


Figure 3. Research Design Diagram

4. Research and Analysis

4.1. Construction of the indicator system

Combining the financial attributes and digital characteristics of digital finance, and drawing on the digital inclusive finance index of Peking University and the urban digital finance indicator system constructed by scholars like Gaoke Liao, this study constructs a digital finance measurement indicator system including four primary indicators (DFS, DFT, DFE and DFAD) and 13 secondary indicators. Following data standardization via averaging method, the processed data are applied to equations (1)-(4), yielding the indicator system and corresponding weights as show in Table3.

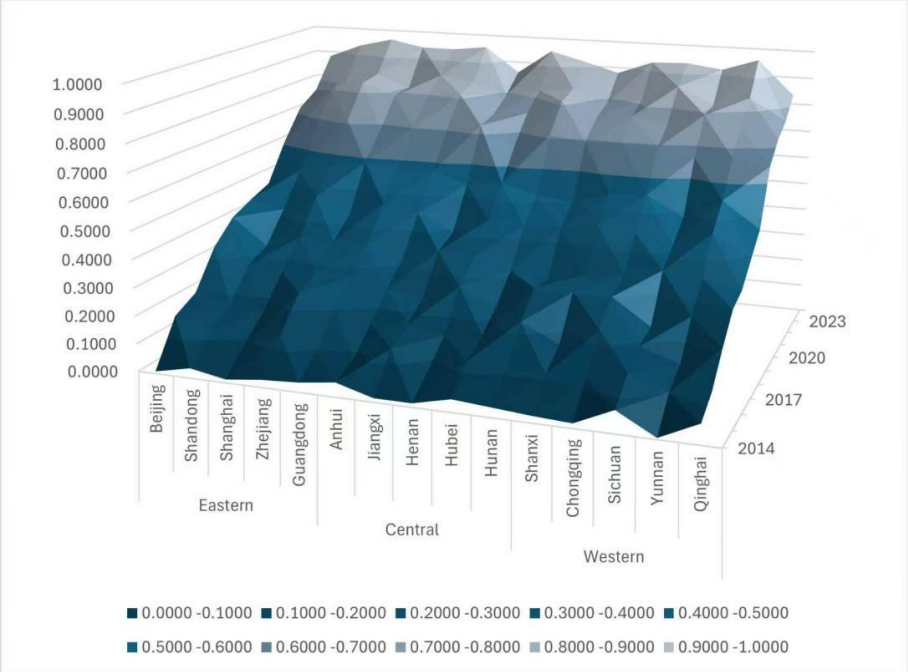
Table 3. Digital Finance Measurement Indicator System (2014-2024)

Primary indicators	Secondary indicators	unit	Weight (%)	Indicator Attributes
Digital Financial Services(A)	Digital payment transaction volume(A1)	100 million yuan	9.58	positive
	Digital lending transaction volume(A2)	100 million yuan	8.97	positive
	Digital insurance transaction volume(A3)	100 million yuan	9.14	positive
Digital Financial Technology(B)	Number of fintech companies(B1)	Home	5.94	positive
	Intensity of investment in scientific and technological R&D(B2)	%	8.90	positive
	Number of patents granted(B3)	item	8.56	positive
Digital Financial Environment(C)	Internet penetration rate(C1)	%	7.27	positive
	Digital finance policy support intensity(C2)	Item	7.67	positive
	Urban lighting index(C3)	index	8.29	positive
Digital Finance Application Depth(D)	Core digital business usage frequency per user(D1)	times/person/ year	9.09	positive
	Business conversion efficiency(D2)	%	8.30	positive
	Inclusive service coverage density(D3)	%	8.30	positive

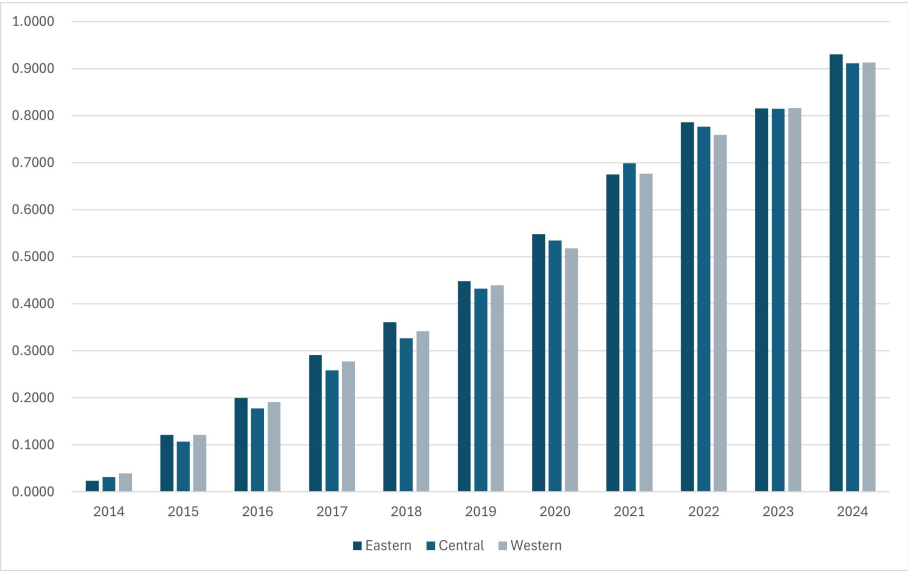
4.2. Comprehensive Analysis

Panel data from 15 provinces and municipalities in eastern, central and western China from 2014 to 2024 are substituted into formulas (1)-(5), and comprehensive measurement is performed using the DFS, DFT, DFE and DFAD indicator systems. Specifically, the comprehensive score of digital finance measurement (2014-2024) shown in Figure 4 can be obtained. Overall, the development of digital finance in China shows a continuous growth trend. The comprehensive scores of the eastern, central and western

regions have all increased from the lower level in 2014 (0.035 in the east, 0.049 in the central region and 0.005 in the west) to the higher level in 2024 (0.935 in the east, 0.880 in the central region and 0.899 in the west). This reflects that under the combined effect of policies, technology and market demand, digital finance has formed a large-scale development trend across the country and becomes an important driving force for promoting financial system reformation and high-quality economic development. From a regional development perspective, from 2014 to 2019, all regions exhibited a balanced development trend with minimal disparities. From 2020 to 2024, the development pace of each region varied, but the gap did not widen significantly. The eastern region steadily improved thanks to its solid industrial base and strong innovation capabilities, while the western region achieved rapid growth benefiting from policy dividends, and the central region experienced a relatively slow growth rate. Specifically, the eastern region performed better overall, followed by the western region, and then the central region.



(a)



(b)

Note: (a) represents the overall score of digital finance measurement in each region (2014-2024), and (b) represents the development trend of the overall score of digital finance measurement (2014-2024).

Figure 4. Overall Score of Digital Finance Measurement (2014-2024)

As the core region for digital finance development in China, the eastern region achieved an overall comprehensive score of 0.931 in 2024, maintaining a leading position for most of the study period. Shanghai and Guangdong stood out, with average scores of 0.963 and 0.937 respectively from 2014 to 2024, serving as the twin engines of digital finance development in the east, while Beijing lagged behind. Shanghai, as an international financial center, possesses significant advantages in usage depth, technological innovation, and service structure. From 2014 to 2024, Shanghai's patent authorizations grew at a rate of 35%, and both the number of fintech companies and patent authorizations remained high, demonstrating outstanding performance in the DFT field. This is mainly because Shanghai has gathered the top financial technology companies in the country. Technological innovation has directly promoted the iterative upgrading of digital credit, insurance and other products, as well as the improvement of the financial market. In 2024, the average frequency of use of core business in Shanghai reached 413.85 times/person, which is significantly higher than other provinces and cities in the east. This is due to its rich digital financial application scenarios and solid infrastructure, which has enabled digital financial services to deeply penetrate into the daily consumption of residents and business operations, forming strong user stickiness [46]. In contrast, Beijing's comprehensive score in 2024 was only 0.881. On the one hand, as the core area of national financial supervision, the primary goal of Beijing's digital financial development is risk prevention and control. The policy focuses on financial security and serving real economy, resulting in a weaker digital financial ecosystem than Shanghai, Guangdong and other places. On the other hand, Beijing's digital financial services are biased towards equity financing and intellectual property pledge and other direct financing methods. The supply of inclusive digital financial services is insufficient, and the scores of indicators such as digital financial transaction scale and inclusive service coverage density are low [47].

For the western region, Chongqing's comprehensive score in 2024 reached 0.932, which is in a leading position in the region. In contrast, Qinghai's comprehensive score in 2024 was only 0.832, and its development level was relatively lagging behind. The development of digital finance in Chongqing is not only prominent in the western region, but also has strong competitiveness in the whole country. There are two main reasons: Firstly, the construction of the Chengdu-Chongqing Twin-City Economic Circle has formed an active urban agglomeration economy, providing a solid economic foundation and a large market demand for the development of digital finance. The Average usage frequency per user for core business and the Business usage conversion efficiency are both high. Secondly, Chongqing is a key node of the Yangtze River Economic Belt and the “Belt and Road initiative”, and has the policy support for the construction of the “Inland International Financial Center”. Its unique location advantage has expanded its scope of international financial cooperation and promoted the innovative development of financial services [48-49]. In comparison, Qinghai's development is relatively weak mainly due to three reasons: Firstly, the geographical features of high altitude and mountainous terrain exacerbate the difficulties in building digital infrastructure; Secondly, financial policies focus more on green finance and inclusive finance, and DFE cannot provide strong support for the development of digital finance; Finally, the industrial structure is dominated by resource-based industries and traditional financial branches, which restricts the expansion of the scale of digital financial businesses and the progress of technological innovation [50-51].

Within the central region, Henan performed well, with a comprehensive score of 0.950 in 2024, while Jiangxi had a lower score, only 0.859 in 2024. As an important manufacturing and agricultural province in central China, Henan has a large-scale demand for scenarios in agricultural production, advanced manufacturing and other fields, which drives the continuous expansion of digital financial business. In 2024, the scale of digital payment business in Henan was RMB 8067.636 billion, the scale of digital credit business was RMB 1631.431 billion, and the scale of digital insurance business was RMB 498.609 billion, all of which have significant advantages in the central region. In addition, the in-depth construction of inclusive finance in Henan provided an important impetus for the development of digital finance. Unique inclusive finance development models such as the “Lankao Model” and the “Lushi Model” have improved the convenience and accessibility of financial services and laid a good foundation for the development of digital finance [52-54]. The main reason for the relatively lagging development of digital finance in Jiangxi Province is the lack of digital financial technology. In 2024, the province had 2,842 financial technology companies, a technology research and development intensity of 1.96%, and 97,372 patents granted, which is relatively weak compared with other provinces and cities in central China.

4.3. Subsystem Analysis

Substituting the data into formulas (1)-(5), we can obtain the digital finance subsystem measurement scores of eastern, central, and western China (2014-2024) shown in Figure 4 and the digital finance

subsystem measurement scores of provinces and cities across regions in China (2014-2024) shown in Figure 5. This study analyzes the three regions separately and explores the scores of each subsystem in each province and city within the three regions in order to discover the development trends and contributions of the subsystems. From the perspective of the subsystem, the comprehensive analysis shows that DFS (composed of three indicators: digital payment transaction volume, digital credit transaction volume, and digital insurance transaction volume) is the core driving force for the development of digital finance, and its score is at the highest level in each region; while DFE (composed of three indicators: Internet penetration rate, digital finance policy support intensity, and city lighting index) is easily affected by infrastructure construction and government policies, and its overall contribution rate is relatively low.

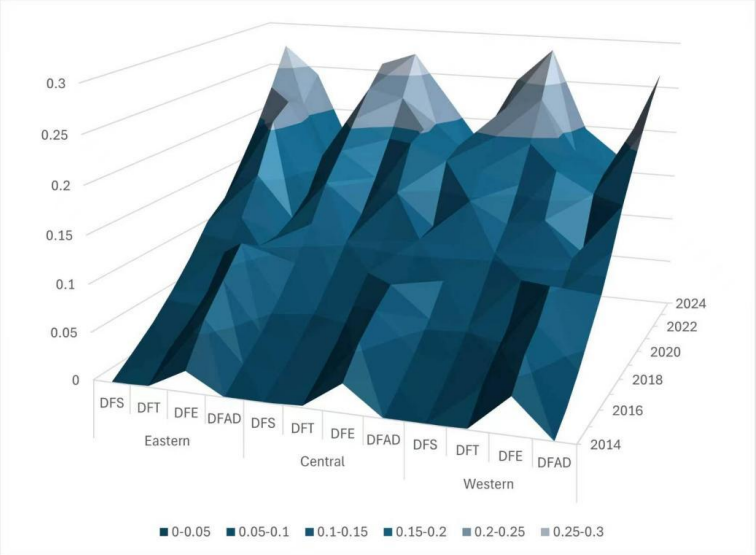
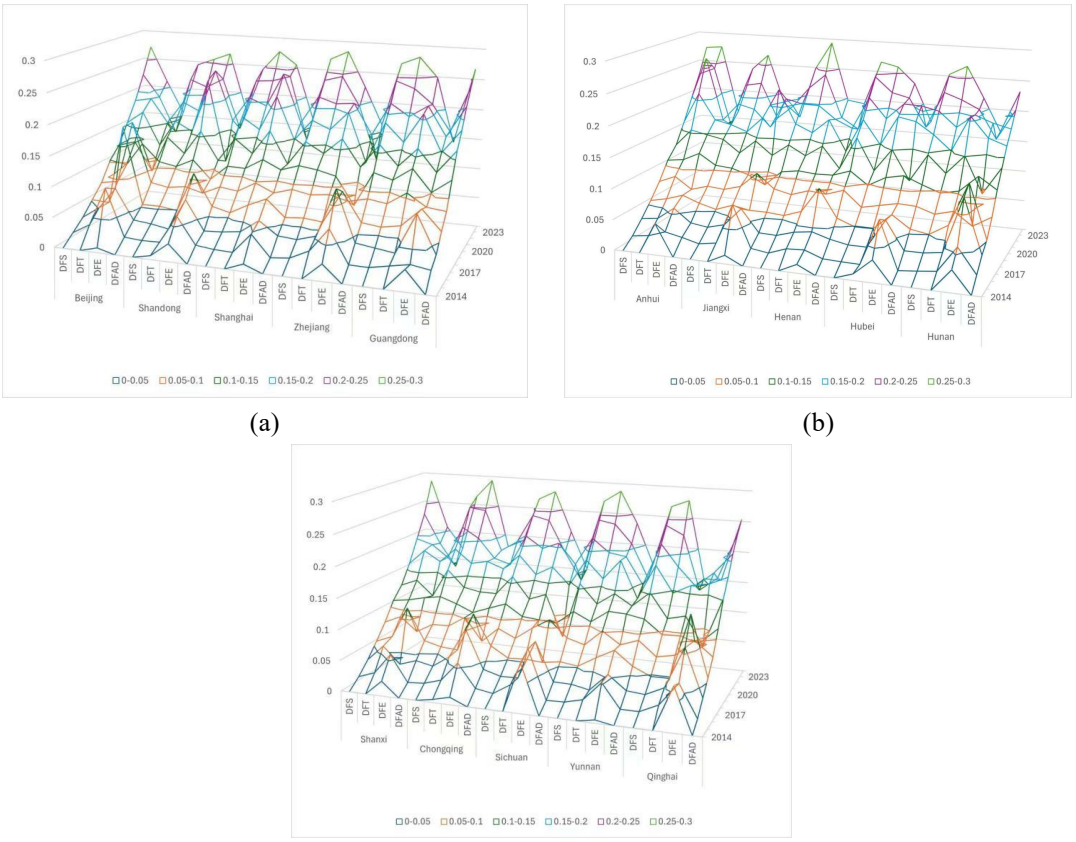


Figure 5. Measurement Scores of Digital Financial Subsystems in Eastern, Central and Western China (2014-2024)

The DFS subsystem comprises three indicators: digital payment transaction volume, digital credit transaction volume, and digital insurance transaction volume. Its scores reflect the market size and supply capacity of digital finance, and are central to its development. As shown in Figure 6, DFS has the highest scores and fastest growth rates in the eastern, central, and western regions. Specifically, Zhejiang and Guangdong in the east, Henan and Anhui in the central region, and Chongqing and Shaanxi in the west perform particularly well in this dimension. The main reasons for the advantages of the DFS subsystem are: Firstly, China's digital payment market is booming. Platforms such as Alipay and WeChat have formed a development model covering various scenarios including personal transfers, offline QR code payments, and utility bill payments. By reducing transaction costs and shortening payment time, the transaction scale and coverage of financial services have been effectively expanded. In 2024, the transaction scale of mobile payment in China reached 672 trillion yuan, which is the core driving force for the rapid development of digital financial services [55-56]. Secondly, relying on big data, cloud computing and artificial intelligence technologies, digital credit has quickly filled the gaps in traditional financial services in terms of service efficiency. The improvement of digital credit information sharing mechanism and the construction of digital social credit platforms (DSCPs) have also reduced information asymmetry in financial services and improved the its availability, leading to the gradual expansion of digital credit market [57-58]. Thirdly, the rapid development of the digital economy has promoted employment and increased residents' income, significantly increasing social insurance fund income and the scale of residents ' insurance participation [59-60]. During the study period, digital payment, credit and insurance businesses in three regions developed rapidly, making DFS subsystem play an important role in fostering the overall development of digital finance.

The DFE subsystem comprises three indicators: internet penetration rate, digital finance policy support intensity, and urban lighting index. It reflects the level of infrastructure development, institutional guarantees, and economic foundation for digital finance development, serving as a foundation of the development of other subsystems. It can be seen from the figures that DFE scored the lowest in all regions and experienced periodic fluctuations during the study period, which is the main reason hindering the development of digital finance across regions. Its lagging development is primarily due to the structural

imbalances of internet penetration although it has generally increased. In rural areas and remote counties, network quality, equipment usage capabilities, and digital literacy remain insufficient; and the state of digital finance infrastructure development varies across regions. Simultaneously, influenced by macroeconomic cycle fluctuations, industrial restructuring, and uneven regional development, some provinces and cities experienced slower economic growth and insufficient market and enterprise vitality during the study period, weakening the supporting role of the economic foundation for digital finance.



(a) (b)

(c)

Note: (a) is the eastern region; (b) is the central region; (c) is the western region.

Figure 6. Measurement Scores of Digital Financial Subsystems across Regions in China (2014-2024)

4.4. Coupling Coordination Analysis

Substituting the standardized data into the coupling coordination model, formulas (6)-(8) were used to calculate the coupling degree, coordination index, and couple coordination degree of the four digital finance subsystems in 15 provinces and cities in eastern, central, and western China from 2014 to 2024 (Table 4 and Figure 7), in order to explore the correlation strength and collaborative development quality among the four subsystems. Overall, the coupling coordination development of China's digital finance subsystems from 2014 to 2024 showed a development trend from imbalance (2014-2016) to coordination (2017-2024), which is consistent with the growth of the comprehensive score of digital finance and the gradual optimization trend of the subsystem structure.

During the study period, the coupling degree C value in each region remained above 0.72, and was stable in the range of 0.95-1.00 in most years, indicating that the subsystems maintained strong interaction and intrinsic connection, and that digital finance development has structural and holistic characteristics. The coordination index T value showed a rapid upward trend, gradually increasing from around 0.01 in the early stage to above 0.90, indicating that with the overall development of digital finance, the coordination between subsystems has been greatly improved. Under the combined effect of the coupling degree C value and the coordination index T value, the coupling coordination degree T value gradually improved, from 0.100 (severe imbalance) in 2014 to 0.989 (good coordination) in 2024, indicating that China's digital finance development has gradually entered a high-quality development stage from a rapid expansion stage.

From a regional perspective, the coordinated development of the digital finance subsystems in eastern,

central, and western regions is highly consistent with the overall national development trend, all transitioning from imbalance (2014-2016) to coordination (2017-2024). However, differences exist in the pace and driving forces. The eastern region possesses a strong foundation of digital economy, a cluster of high-end industries, and a high level of digital literacy among its residents. Coupled with pioneering policies such as the digital RMB pilot program and the fintech innovation regulatory pilot program, the four subsystems have developed in a coordinated manner. The coupling coordination degree (D-value) increased from 0.100 in 2014 to 0.991 in 2024, showing the earliest and most mature growth in coupling coordination. The central region's growth trend in coupling degree and coordination index is roughly the same as the eastern region, but the improvement in coordination level lags slightly behind the east by 1-2 years. This is mainly because the central region has absorbed substantial industrial relocation. At the same time, supported by policies such as digital villages and inclusive finance, it has achieved remarkable results in rural digital credit and county-level digital financial services. As a result, regional gaps in digital infrastructure have been gradually narrowed and coordination between subsystems has been enhanced. The western region maintained a similar development trend. Despite challenges such as inadequate infrastructure and a constrained industrial structure, supported by policies including rural revitalization and financial backing for the new Western Land-Sea Corridor, the four subsystems also shown rapid growth and synergistic development in the later period.

Table 4. Coupling Coordination Degree of Digital Financial Subsystems in Eastern, Central and Western China (2014-2024)

partition	years	Coupling degree C value	Coordination Index T value	Coupling coordination degree D value	Coupling and Coordination Degree
Comprehensive	2014	1.000	0.010	0.100	Severe Disorder
	2015	0.883	0.118	0.323	Mild Disorder
	2016	0.917	0.204	0.433	On the Verge of Disorder
	2017	0.933	0.306	0.534	Barely Coordination
	2018	0.988	0.363	0.599	Barely Coordination
	2019	0.992	0.471	0.683	Primary Coordination
	2020	0.991	0.567	0.749	Intermediate Coordination
	2021	0.985	0.749	0.859	Good Coordination
	2022	0.991	0.849	0.917	High-quality Coordination
	2023	0.999	0.870	0.932	High-quality Coordination
	2024	1.000	0.978	0.989	High-quality Coordination
Eastern	2014	1.000	0.010	0.100	Severe Disorder
	2015	0.727	0.270	0.443	On the Verge of Disorder
	2016	0.860	0.231	0.446	On the Verge of Disorder
	2017	0.883	0.340	0.548	Barely Coordinated
	2018	0.970	0.395	0.619	Primary Coordination
	2019	0.993	0.479	0.690	Primary Coordination
	2020	0.992	0.583	0.760	Intermediate Coordination
	2021	0.990	0.718	0.843	Good Coordination
	2022	0.991	0.851	0.919	High-quality Coordination
	2023	0.999	0.856	0.925	High-quality Coordination
	2024	1.000	0.981	0.991	High-quality Coordination
Central	2014	1.000	0.010	0.100	Severe Disorder
	2015	0.917	0.101	0.304	Mild Disorder
	2016	0.950	0.181	0.415	On the Verge of Disorder
	2017	0.971	0.271	0.513	Barely Coordination
	2018	0.995	0.335	0.577	Barely Coordination
	2019	0.993	0.458	0.674	Primary Coordination
	2020	0.990	0.565	0.748	Intermediate Coordination
	2021	0.980	0.766	0.867	Good Coordination
	2022	0.991	0.845	0.915	High-quality Coordination
	2023	0.999	0.865	0.930	High-quality Coordination
	2024	0.999	0.964	0.981	High-quality Coordination
Western	2014	1.000	0.010	0.100	Severe Disorder
	2015	0.879	0.119	0.324	Mild Disorder
	2016	0.933	0.202	0.434	On the Verge of Disorder
	2017	0.933	0.310	0.538	Barely Coordination
	2018	0.981	0.362	0.596	Barely Coordination
	2019	0.989	0.476	0.686	Primary Coordination
	2020	0.987	0.551	0.737	Intermediate Coordination
	2021	0.981	0.761	0.864	Good Coordination

2022	0.991	0.847	0.916	High-quality Coordination
2023	0.999	0.889	0.943	High-quality Coordination
2024	1.000	0.990	0.995	High-quality Coordination

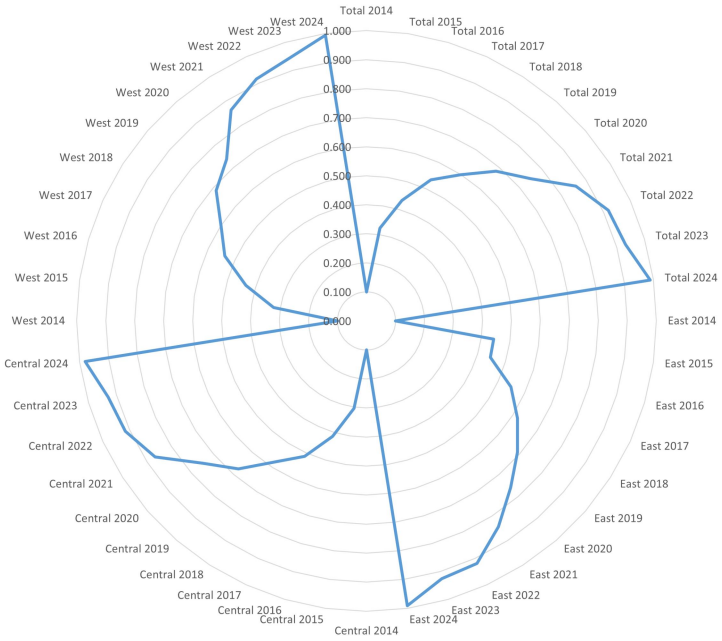


Figure 7. Trend of Coupling Coordination Degree of Digital Financial Subsystems in Eastern, Central and Western China (2014-2024)

4.5. Grey Relational Analysis

We input the comprehensive scores into the grey relational model and calculate correlation scores using formula (9)-(11). This yields the correlation scores between the secondary digital finance indicators and the overall level for the 15 provinces and cities in eastern, central and western China from 2014-2024 (Table 5), as well as the correlation scores for China's overall digital finance development (Table 6). To analyze the grey relational degrees of these secondary indicators, this study selects six evenly spaced years: 2014, 2016, 2018, 2020, 2022 and 2024, so as to identify the contribution and correlation of each indicator across regions.

The top-ranked indicators generally show a trend from C (DFE) to B (DFT), and finally back to A (DFS), which conforms to the objective laws of development from relying on policies to developing technology and then to enriching scenarios. At the beginning of the study, the top-ranked indicator in the East, Central and Western regions was C2 (digital finance policy support intensity), and the correlation score was 1.000, indicating that it was the main driving force for the initial development of digital finance. Specifically, the East laid the foundation for future development by taking advantage of policies like pilot program for fintech innovation, and the Central region benefited from downward extension of inclusive finance. In 2018, the top-ranked indicator in the Central region changed to C3 (urban lighting index). It was mainly due to the gradual weakening of the marginal effect of policies and the effect of receiving industrial transfer from the East in that year, resulting in a significant increase in real economy activity. In the mid-term of the study (2020-2022), the leading indicator for both the eastern and central regions shifted to B3 (number of patents granted). With the gradual improvement of the policy framework, fintech began to drive the iterative upgrades of technologies such as risk control, payment, and credit, becoming a core driving force for the development of digital finance. However, by the end of the study (2024), the core indicator for all three regions had reverted to A1 (digital payment transaction volume), indicating that the development of digital finance ultimately serves the real economy. As the most basic digital financial service scenario, the continuous expansion of digital payment transaction volume not only directly reflects the activity level of digital financial services but also serves as a crucial force for the development of digital finance. Compared to the eastern and central regions, the western region exhibits a development trend of C2 (digital financial policy support intensity) - B2 (intensity of investment in scientific and technological R&D) - D3 (inclusive service coverage intensity) - A1 (digital payment transaction volume). The subtle differences are mainly due to the following reasons. Firstly, digital finance in the west started later, and the coverage of traditional financial services is relatively low. After the implementation of policies, technological innovation cannot be directly achieved through the

transformation of technological achievements such as patents. It is necessary to first make up for the technological shortcomings by strengthening R&D investment, making R&D investment a crucial link in the development process. Secondly, the western region has a higher proportion of counties and rural areas. Since an important aspect of digital finance development is to expand service coverage, after making up for the technological shortcomings, inclusive service coverage density becomes the leading indicator in terms of contribution.

The second-ranked indicator shows significant regional differences. In the eastern region, the second-ranked indicator follows a development trend of B2 (intensity of investment in scientific and technological R&D) - C1 (internet penetration rate) - C3 (urban lighting index) - D2 (business conversion efficiency) - B2 (intensity of investment in scientific and technological R&D). In the central region, the second-ranked indicator follows a development trend of B2 (intensity of investment in scientific and technological R&D) - B1 (number of fintech companies) - D3 (inclusive service coverage density) - B2 (intensity of investment in scientific and technological R&D) - A3 (digital insurance transaction volume). In the western region, the second-ranked indicator follows a development trend of C3 (urban lighting index) - B1 (number of fintech companies) - D3 (inclusive service coverage density) - D2 (business conversion efficiency) - C3 (urban lighting index) - A2 (digital credit transaction volume). Although regional differences exist, the second-ranked indicator in each region generally follows a development trend from DFT to DFE and DFAD, and then to DFS, similar to the development trend of the indicator with the highest contribution rate.

The third-ranked indicator also shows significant regional differences as well. The development trend in the eastern region is C3 (urban lighting index) - B1 (number of fintech companies) - D3 (inclusive service coverage density) - D2 (business conversion efficiency) - D1 (core digital business usage frequency per user). The development trend in the central region is C3 (urban lighting index) - D3 (inclusive service coverage density) - C1 (internet penetration rate) - D2 (business conversion efficiency) - C1 (internet penetration rate) - B2 (intensity of investment in scientific and technological R&D). The development trend in the western region is B2 (intensity of investment in scientific and technological R&D) - B3 (number of patents granted) - B1 (number of fintech companies)/C1 (internet penetration rate) - B3 (number of patents granted) - D2 (business conversion efficiency) - D1 (core digital business usage frequency per user). The development trend of the third-ranked indicator differs slightly from the top two, primarily focusing on the DFT and DFAD, playing a crucial supplementary and supporting role.

Table 5. Grey Relationship of Secondary Indicators of Digital Finance in Eastern, Central and Western China (2014-2024)

area	years	Sort	1	2	3
east	2014	Secondary indicators	C2	B2	C3
		Relevance score	1.000	0.642	0.629
	2016	Secondary indicators	C2	C1	B1
		Relevance score	1.000	0.590	0.532
	2018	Secondary indicators	C2	C3	B1
		Relevance score	1.000	0.828	0.788
	2020	Secondary indicators	B3	D2	D3
		Relevance score	1.000	0.754	0.739
	2022	Secondary indicators	B3	B2	D2
		Relevance score	1.000	0.809	0.678
	2024	Secondary indicators	A1	B2	D1
		Relevance score	1.000	0.924	0.918
Central	2014	Secondary indicators	C2	B2	C3
		Relevance score	1.000	0.620	0.614
	2016	Secondary indicators	C2	B1	D3
		Relevance score	1.000	0.548	0.524
	2018	Secondary indicators	C3	D3	C1
		Relevance score	1.000	0.946	0.938
	2020	Secondary indicators	B3	D3	D2
		Relevance score	1.000	0.832	0.820
	2022	Secondary indicators	B3	B2	C1
		Relevance score	1.000	0.882	0.791
	2024	Secondary indicators	A1	A3	B2
		Relevance score	1.000	0.916	0.903
west	2014	Secondary indicators	C2	C3	B2
		Relevance score	1.000	0.555	0.549
	2016	Secondary indicators	C2	B1	B3
		Relevance score	1.000	0.550	0.547
	2018	Secondary indicators	B2	D3	B1, C1
		Relevance score	1.000	0.907	0.883
	2020	Secondary indicators	D3	D2	B3

2022	Relevance score	1.000	0.915	0.816
	Secondary indicators	D3	C3	D2
2024	Relevance score	1.000	0.989	0.939
	Secondary indicators	A1	A2	D1
	Relevance score	1.000	0.893	0.892

By treating the three regions as a whole and conducting a comprehensive analysis, it can be found that the trend of the top-ranked indicator is C (DFE, specifically internet penetration rate, digital finance policy support intensity and urban lighting index) - B (DFT, specifically number of fintech companies, intensity of investment in scientific and technological R&D and number of patents granted) - A (DFS, specifically digital payment transaction volume, digital lending transaction volume and digital insurance transaction volume). This is consistent with the trends in the eastern and central regions, indicating that the changes in the eastern and central regions are more representative of the overall trend.

The trend of the second-ranked indicator is B - C - B - D - B - A, which is highly similar to that of the central region. This similarity is mainly due to the fact that development of digital finance in central region and the whole country largely relies on the innovative development of DFT. The second-ranked indicator has long fluctuated around the DFT dimension, reflecting the fundamental role of technological innovation. Meanwhile, in the middle stage of development, indicators such as internet penetration rate and inclusive service coverage density were also interspersed, while in the final stage, the focus shifted to DFS indicators such as digital insurance transaction volume. This reflects the characteristics of the central region and the whole country in focusing on inclusive services and coordinated improvement in the process of digital finance development.

The trend of third-ranked indicator C - B - C - D is highly similar to that of the eastern region. The main reason is that the eastern region has maintained a high level of urban economic vitality, technological innovation capability and user penetration throughout the development process. Its mature digital finance ecosystem provides stable support for the digital finance development nationwide. As a result, the third-ranked indicator constantly centers on the optimization of DFE, technology innovation and the improvement of service efficiency.

Table 6. Grey Relationship Degree of Secondary Indicators of China's Overall Digital Finance (Representative Years)

years	Sort	1	2	3
2014	index	C2	B2	C3
	Relevance score	1.0000	0.599	0.596
2016	index	C2	C1	B1
	Relevance score	1.0000	0.5480	0.5440
2018	index	C3	B1	C2
	Relevance score	1.0000	0.9800	0.9790
2020	index	B3	D3	D2
	Relevance score	1.0000	0.9100	0.8860
2022	index	B3	B2	D2
	Relevance score	1.0000	0.9080	0.8390
2024	index	A1	A3	D1
	Relevance score	1.0000	0.9030	0.8930

5. Conclusion and Discussion

Based on the preceding analysis of the overall development, subsystem development, coupling coordination degree, and grey relational degree of digital finance in China as a whole and in the eastern, central, and western regions, this study mainly draws the following four core conclusions: 1) The development level of digital finance in China has shown a continuous upward trend both overall and in its parts. In 2014, the average comprehensive scores of the eastern, central, and western regions were 0.023, 0.032, and 0.039, respectively. By 2024, the average scores had increased to 0.931, 0.911, and 0.913, with growth rates of 39.76%, 28.57%, and 23.22%. The eastern region maintains an advantageous position in both comprehensive score and growth rate; 2) For the four subsystems, DFS, DFT, DFE, and DFAD show similar growth trends overall and regionally, but the development of each subsystem varies. Among them, the DFS subsystem is the core driving force for the development of digital finance, with a total score of 0.831 in 2024. DFAD comes second, with a total score of 0.770 in 2024. The following are DFT and DFE, with total scores of 0.660 and 0.494 respectively in 2024. 3) From 2014 to 2024, the degree of coupling and coordination among the subsystems showed a shift from imbalance to coordination. 2014-2016 was the imbalance stage (D_{2014}=0.100, D_{2015}=0.323, D_{2016}=0.433), while 2017-2024 was the coordination stage (D_{2017}=0.534, D_{2018}=0.599, D_{2019}=0.683, D_{2020}=0.749, D_{2021}=0.859,

D_{2022}=917, D_{2023}=0.932, D_{2024}=0.989). Analysis of each region reveals that the coupling and coordination levels in the east, central, and west maintain roughly similar development trends, but differ slightly in their development pace, with the central and western regions lagging slightly behind the east by 1-2 years; 4) Grey relational analysis reveals that among the top three contributing indicators of each subsystem from 2014 to 2024, the proportions of DFS, DFT, DFE, and DFAD indicators are 11.11%, 33.33%, 33.33%, and 22.22%, respectively. The top-ranked indicators by contribution exhibits an overall trend of C(1.000) - B(1.000) - A(1.000), which is highly consistent with the performance of eastern and central regions. The second-ranked indicators follow a trend of B(0.599) - C(0.548) - B(0.980) - D(0.910) - B(0.908) - A(0.903), which is largely in line with that of the central region. Meanwhile, the third-ranked indicator shows a trend of C(0.596) - B(0.544) - C(0.979) - D(0.886, 0.839, 0.893), which is relatively similar to the trend in the eastern region. Regarding the development of each subsystem, the DFS and DFAD subsystems have a relatively good foundation and can form a synergistic effect in terms of service scale, efficiency, and inclusive coverage in the later stages. For regional development, the leading position of eastern region should be consolidated, and the development of central and western regions should be driven by technological innovation and inclusive services. According to grey relational analysis, the core driving force of digital finance development presents a dynamic change of policy, technology, and services. Differentiated policies should be implemented to promote the coordinated development of digital finance, following the objective laws of development. This study, limited by research time and data sources, mainly uses provincial panel data and lacks field research and long-term tracking analysis, resulting in insufficient attention to practical application. So going forward, with technological iteration and data diversification, future research can incorperate new productive forces, regional policies, and fintech upgrading. Greater focus may by placed on micro-enterprises and county-level analyses to strengthen tracking and dynamic research, thereby enhancing the practicality and reference value of the research.

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