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Research on the Coupling Coordination and Impact Mechanism between Digital Inclusive Finance and Regional Innovation Capability in the Yangtze River Economic Belt

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Abstract:

This paper analyzes panel data from 2013 to 2022 covering 11 provinces and cities within the Yangtze River Economic Belt. It establishes a holistic assessment framework for Digital Inclusive Finance (DIF) and Regional Innovation Capability (RIC), calculates RIC using the entropy method, and explores the coupling coordination degree between DIF and RIC using the coupling coordination model. In the end, the paper examines the influencing mechanism between the two variables using the Spatial Autoregressive Model (SAR). The study reveals that from 2013 to 2022, DIF and RIC in the upper, central, and lower regions of the Yangtze River Economic Belt exhibited steady growth, though with significant regional disparities and varying development rates. Most cities in this Belt are experiencing a steady ascending trajectory in the coupling coordination between DIF and RIC. However, most provinces are categorized within the range of poorly coordinated and primarily coordinated levels of coupling. The economic foundation, education level, information development level, and foreign trade level positively influence the coupling coordination between DIF and RIC, while the intensity of technological support and the level of industrial structure hinder their coupled coordinated development.

Keywords: digital inclusive finance. regional innovation. coupling coordination. spatial autocorrelation.

INTRODUCTION

In the context of Chinese-style modernization, innovation is considered a primary driver of economic development[1]. However, innovative activities are often characterized by high risks, long cycles, and unstable returns[2] , which can limit access to the financial system for some innovators. As a result, they may face financial exclusion, which restricts their ability to obtain necessary financial services[3]. Therefore, the Chinese government is committed to developing *DIF*. On one hand, its unique internet attributes reduce time and transaction costs. On the other hand, digitization transcends geographical barriers. It also reduces the barriers to financial services and mitigating financial exclusion[4]. Furthermore, the 'digital nature' of *DIF* necessitates that its core competitiveness relies on technological innovation[5]. As a result, there is a mutually influential and interdependent coupling relationship between *DIF* and innovation. If both can develop in a coordinated and coupled manner, it would contribute to a positive development situation where digital inclusive finance supports innovation, and innovation, in turn, bolsters *DIF*, which is of significant practical importance to China's economic development. Enhancing national innovation capabilities is inseparable from improving *RIC*, which can serve as a new driving force for building the national innovation system[6]. Therefore, it is crucial to explore how *DIF* and *RIC* mutually influence each other, how to enhance their coordinated development, what factors affect their coordinated development capability, and how to strengthen their integration. These questions are worthy of in-depth research and discussion.

Current academic research on *DIF* and *RIC* predominantly emphasizes the impact of *DIF* on *RIC*. This research primarily centers on the following areas:

1. **Impact Mechanism:** The development of *DIF* can enhance financial efficiency and the level of marketization, thereby promoting the development of *RIC*[7]. Concurrently, *DIF* can also foster the development of *RIC* by impacting the development level of regional digital economic[8], not only helping to distribute credit resources, but also enhancing the amount and standard of consumer spending[9].

2. **Impact Effects:** The impact of *DIF* on *RIC* is nonlinear, exhibiting a clear distinct threshold characteristic, with its impact diminishing gradually after crossing the threshold value[10]. However, some research findings suggest that the driving effect of *DIF* on *RIC* becomes more prominant only after surpassing the threshold[11]. The reason for these contradictory research outcomes may be the selection of different threshold variables.

3. **Different Perspectives:** From the viewpoint of resource allocation, the impact of *DIF* on *RIC* is highly significant, but the efficiency of financial resource allocation has a masking effect in this process, showing a negative correlation with

RIC[12]. From the analysis of internal supply and external demand perspectives, *DIF* primarily enhances the provision of human capital and the external demand generated by industrial upgrading, thereby accelerating the enhancement of *RIC*[13].

Research on the impact of innovation on *DIF* is not yet abundant in academic circles. Some studies have found that advancements in technological innovation lead to the generation of new technologies, products, and business models, which can enhance production efficiency and reduce transaction costs. This process drives the upward development of *DIF*, thereby accelerating the effectiveness of digital new quality productive forces[14]. Additionally, there is a bidirectional promotional effect and spatial interaction between *DIF* and *RIC*. *DIF* in one region can suppress the development of *RIC* in neighboring areas, and conversely, the development of *RIC* can also suppress *DIF* in neighboring regions[15]. Former People's Bank of China Governor, Zhou Xiaochuan, proposed during the COVID-19 pandemic that technological innovation can stimulate the development of *DIF.* These findings can also serve as references for this paper[16].

In summary, current examination of the relationship between *DIF* and *RIC* primarily focuses on the unilateral impact of *DIF* on *RIC*, with few studies addressing the influence of *RIC* on *DIF* and their interactive relationship. In light of this, this paper selects panel data from 41 cities in China's Yangtze River Economic Belt from 2013 to 2022 to analyze the coupling relationship between *DIF* and *RIC*. The paper adopts the coupling coordination degree and a Spatial Autoregressive Model (SAR) to analyze the coupling coordination degree and its influencing mechanisms between *DIF* and *RIC* in the Yangtze River Economic Belt. This study delivers the following pivotal contributions:

(1) It expounds the theoretical framework of the coupling and coordination development between *DIF* and *RIC*. Current theoretical research on *DIF* and *RIC* primarily concentrates on *DIF* affects *RIC*, without providing a theoretical mechanism analysis of their mutual influence. This research provides an analysis to investigate the interconnection of the coupling and coordination between *DIF* and *RIC*, offering theoretical insights into the study of their interrelationship.

(2) It measures the coupling coordination degree between *DIF* and *RIC* in the Yangtze River Economic Belt and analyzed the influencing mechanisms of this coupling coordination degree. Through this, it also measures the relation between *DIF* and *RIC* in the region and carries out a thorough investigation of their interaction. Additionally, The Special Autoregressive Model (SAR) is adopted for analyzing the factors influencing the coupling coordination between the two, providing a valuable reference for research in this field.

(3) It broadens the research scope on the coupling coordination between *DIF* and *RIC*. While the majority current researches centers on the national level, this study examines the Yangtze River Economic Belt—a key region in China's coordinated development strategy—thereby contributing to regional development and enriching research on the *DIF-RIC* relationship.

THE COUPLING MECHANISM BETWEEN DIGITAL INCLUSIVE FINANCE AND REGIONAL INNOVATION CAPABILITIES

The coupling mechanism between digital *DIF* and *RIC* can be described as follows: First, *DIF* can promote the development of *RIC*. Capital investment is a key in determining regional innovation output and providing a strong momentum for innovation. The expansion of *DIF* enables innovation entities, previously excluded from traditional financial services due to asset size or volume, to bypass the high thresholds imposed by conventional financial institutions. This alleviates funding shortages. This contributes to enhance *RIC*[17]. By regional innovation, small and medium-sized enterprises (SMEs) and other innovative entities, as key players, can contribute significantly. However, they commonly face issues such as high financing costs, difficulty in obtaining financing, and low financing efficiency[18]. *DIF*, relying on big data and the internet, reduces the financing costs and difficulties for SMEs and other innovative entities. Furthermore, by leveraging digital platforms, it efficiently integrates market information, improving the use of resource, solving issues of information asymmetry between financial institutions and SMEs, and enhancing financing efficiency[19]. Additionally, *DIF*, transcends geographical constraints, opening the pathways for innovation entities to access capital. This allows previously underserved entities to obtain financial services, promoting *RIC*[20]. Conversely, the development of *RIC* fosters the advancement of *DIF*. Regional innovation, as a long-term process, requires substantial human, financial, and material resources, accompanied by high levels of risks. These characteristics mean that innovation activities demand significant financial support. Therefore, the improvement of *RIC* continuously stimulates the demand for *DIF*, encouraging its expansion[21]. Moreover, the enhancement of *RIC* increases technological efficiency, providing the technical foundation for the development of *DIF*. Thus, the relationship between *DIF* and *RIC* is characterized by reciprocal influence and promotion. Studying the coupling coordination between *DFI* and *RIC* is highly significant.

CONSTRUCTION OF THE INDICATOR SYSTEM AND ANALYSIS OF RESULTS

Research Subjects

The Yangtze River Economic Belt includes one primary central city, nine secondary central cities, fifteen regional central cities, and fourteen general cities. The urban system displays a distinct pyramid-shaped distribution, with a relatively rational structure. The primary and secondary central cities are in the downstream coastal areas of the region, where urban spatial expansion and the level of urbanization have already reached an advanced stage. The middle and upper reaches contain two secondary central cities, but the majority are general cities. The distribution of cities in the region is shown in Table 1.

Table 1. Urban distribution information in the Yangtze River economic belt

Urban Hierarchy	Cities	Number of Cities
Primary Central Cities	ShangHai	1
Secondary Central Cities	ChongQing, NanJing, Wuhan, Suzhou, Hangzhou, Nanchang, Chengdu, Wuxi, Ningbo, Changsha, Hefei	11
Regional Central Cities	Nantong, Yangzhou, Changzhou, Zhenjiang, Zhoushan, Wuhu, Anqing, Tongling, Chizhou, Jiujiang, Yueyang, Huangshi, Yichang, Luzhou, Yibin	15
General Cities	Wanzhou, Fuling, Jiangjin, Jingzhou, Panzhihua, Jiaxing, Huanggang, Chaohu, Huzhou, Ma'anshan, Shaoxing, Ezhou, Xanning, Shuifu	14

The key region can be categorized into three key parts: the Yangtze River Delta urban agglomeration as the leading area, the central Yangtze River urban agglomeration as the central region, and the Chengdu-Chongqing urban agglomeration as the trailing area. This geographical division corresponds to the upper, central, and lower areas, respectively.

Accordingly, this study analyzes 11 provinces and municipalities within the Yangtze River Economic Belt, categorizing them into upper, central, and lower regions, as shown in Table 2. Panel data from 2013 to 2022 for these cities are utilized for empirical analysis.

Table 2. Regional classification of provinces and municipalities in the Yangtze River economic belt

Region	Cities	Number of Cities
Upstream	Sichuan Province, Chongqing Municipality, Yunnan Province, Guizhou Province	4
Midstream	Hunan Province, Hubei Province, Jiangxi Province	3
Downstream	Shanghai Municipality, Anhui Province, Jiangsu Province, Zhejiang Province	4

Construction of the Comprehensive Evaluation Indicator System

Selection of evaluation indicators

Drawing on existing research, this paper utilizes the "Digital Inclusive Finance Index" developed by the Digital Inclusive Finance Research Center of Peking University and the Ant Group Research Institute as the primary indicator for assessing the level of *DIF* development. The analysis primarily focuses on evaluating the *DIF* development across 11 provinces and municipalities within the region.

Table 3. Construction of comprehensive evaluation indicators

	Primary Indicators	**Secondary Indicators**	**Indicator Measurement**
Regional Innovation	Innovation Input	Research Expenditure Intensity	
		Scale of Researchers	
	Innovation Output	High-tech Industry Revenue Level	
		Innovation Achievements	
	Innovation Environment	Level of Informationization	
		Research and Development Level	
Digital Inclusive Finance	Coverage Extent	Refer to "Peking University Digital Inclusive Finance Index"	
	Usage Depth		
	Digitalization Level		

The comprehensive evaluation system for regional innovation development is built according to three dimensions: innovation input, output, and environment. The three-level indicators are selected based on the scientificity, accuracy, and availability of data, as detailed in Table 3.

Data sources

The data utilized in this study spans the period from 2013 to 2022 and focuses on 12 cities in the Yangtze River Economic Belt. The primary data sources include the *China Statistical Yearbook, China Education Statistical Yearbook 1986-2022*, the National Intellectual Property Administration, the China National Research Data Service Platform (CNRDS), and the *China Regional Statistical Yearbook*. The inter-city distances are computed using the PySAL toolkit in Python software.

Comprehensive Score Calculation

The weights for the various *DIF* indicators are derived from the "Digital Inclusive Finance Index" jointly developed by the Peking University Digital Inclusive Finance Research Center and Ant Group Research Institute. The entropy methods is adopted to compute weights assigned for regional innovation indicators. The calculation process is outlined below:

Standardization of raw data

Given the diversity of variables and units in the established indicator system, the panel data is first normalized. The formula for this process is as follows:

$$x_{ij} = \frac{x_{ij} - min(x_j)}{max(x_j) - min(x_j)} \tag{1}$$

Where x_{ij} represents the value of the j-th indicator for the i-th sample, $max(x_j)$ is the maximum value of the j-th indicator, and $min(x_j)$ is the minimum value of the j-th indicator. This operation normalizes all indicator scores of the samples to a range between 0 and 1, thereby eliminating the impact of different units of measurement across indicators.

Determining weights

The proportion of each indicator is calculated using the following formula:

$$p_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{n} x'_{ij}} \tag{2}$$

Entropy calculation

The entropy value of each indicator is calculated in the following formula:

$$e_j = -\frac{1}{\ln(n)} \sum_{i=1}^{n} p_{ij} ln p_{ij}, j = 1,2,3 \dots \dots, m \tag{3}$$

Where p_{ij} represents the normalized value of indicator j for sample i.

Calculation of indicator weights

The weight of each indicator is computed using the following formula:

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

Comprehensive score calculation

Finally, the comprehensive score for each indicator is derived as follows:

$$U_i = \sum_{j=1}^{m} (W_j \times x'_{ij}) \tag{5}$$

Where U_i represents the comprehensive score, and its range is between [0,1]. The closer the score is to 1, the stronger regional innovation capability is, while a score closer to 0 reflects weaker regional innovation capability.

Analysis of Measurement Results

Analysis of digital inclusive finance measurement results

Building on existing research, this study utilizes the "Digital Inclusive Finance Index" developed by Peking University Digital Inclusive Finance Research Center and Ant Group Research Institute as a metric to evaluate *DIF* development level. The analysis focuses on accessing *DIF* development level across 11 provinces and municipalities within the region.

(1) Analysis of digital inclusive finance measurement results

Based on data from the Peking University Digital Inclusive Finance Research Center, panel data from 34 cities within the region, spanning 2013 to 2022, has been compiled. In this analysis, the 11 provinces and municipalities are categorized by the upper, central, and lower regions. Table 4 presents the *DIF* measurement results in the upstream provinces and municipalities of the region (2013-2022).

Table 4. Digital inclusive finance measurement results for upstream provinces and cities in the Yangtze River economic belt (2013–2022)

Year	Chongqing City	Sichuan Province	Yunnan Province	Guizhou Province
2013	159.8600	153.0400	137.9000	121.2200
2014	184.7100	173.8200	164.0500	154.6200
2015	221.8400	215.4800	203.7600	193.2900
2016	233.8881	225.4146	217.3378	209.4548
2017	276.3056	267.7968	256.2732	251.4571
2018	301.5320	294.3042	285.7906	276.9097
2019	325.4710	317.1103	303.4609	293.5114
2020	344.7642	334.8228	318.4776	307.9366
2021	373.2232	363.6076	346.9307	340.7975
2022	382.2257	371.6112	354.7062	344.6822

Upon examining Table 4, it is observed that the *DIF* data level in Chongqing is close to that of Sichuan Province and higher than that of Yunnan and Guizhou Provinces. Additionally, the *DIF* index in the upper reaches of the region shows a continuous upward trend.

Table 5. Digital inclusive finance calculation results for central region cities of the Yangtze River economic belt (2011-2022)

Year	Hubei Province	Hunan Province	Jiangxi Province
2013	164.7600	147.7100	146.1300
2014	190.1400	167.2700	175.6900
2015	226.7500	206.3800	208.3500
2016	239.8553	217.6911	223.7554
2017	285.2769	261.1176	267.1677
2018	319.4768	286.8088	296.2276
2019	344.4025	310.8504	319.1299
2020	358.6358	332.0348	340.6109
2021	391.9015	362.3647	372.1736
2022	398.8103	371.9490	378.8288

From Table 5, it can be observed that the *DIF* indicators of Hubei, Hunan, and Jiangxi provinces have fluctuated. Among them, Hubei Province has maintained a relatively high level in most years, with a peak value of 398.8103 reached in 2022, the highest in nearly a decade. The *DIF* index of Jiangxi Province is close to that of Hunan Province, slightly lower than that of Hubei. Overall, the *DIF* index in the center of the region shows a general upward trend.

Table 6. Finance calculation results for downstream cities of the Yangtze River economic belt (2011-2019)

Year	Anhui Province	Jiangsu Province	Shanghai Municipality	Zhejiang Province
2013	150.8300	180.9800	222.1400	205.7700
2014	180.5900	204.1600	239.5300	224.4500
2015	211.2800	244.0100	278.1100	264.8500
2016	228.7783	253.7529	282.2235	268.1048
2017	271.5963	297.6881	336.6505	318.0519
2018	303.8302	334.0213	377.7337	357.4451
2019	330.2899	361.9268	410.2814	387.4877
2020	350.1646	381.6125	431.9275	406.8779
2021	384.6236	412.9212	458.9703	434.6098
2022	393.3208	424.0648	460.6908	440.0446

From Table 6, it is evident that there is obvious disparity in the level of *DIF* development among the lower provinces and municipalities of the region. Shanghai, Jiangsu, and Zhejiang demonstrate relatively *DIF* high levels, all surpassing 400, with Shanghai reaching a peak value of 460.6908.

The *DIF* levels of Jiangsu and Zhejiang are comparable, both lower than Shanghai's but higher than Anhui's. Overall, these provinces exhibit an upward trend in *DIF* development. Anhui's *DIF* level is the lowest among the downstream region, although it still exhibits a general growth trend.

(2) Spatial autocorrelation analysis of digital inclusive finance

Based on the calculated Digital Inclusive Finance Index, the *DIF* development levels of the 11 provinces and municipalities in the region from 2013 to 2022 are analyzed by calculating the Moran's I index. This analysis examines the spatial-temporal evolution of *DIF* development across the provinces and cities in the region.

Table 7. Moran's I index of digital inclusive finance development levels in the provinces and cities of the Yangtze River economic belt

Year	Moran's I	P-value
2013	0.4229	0.0034
2014	0.4750	0.0015
2015	0.4247	0.0036
2016	0.4655	0.0019
2017	0.4540	0.0020
2018	0.4990	0.0010
2019	0.5243	0.0006
2020	0.5463	0.0004
2021	0.5854	0.0002
2022	0.6107	0.0001

Based on the data presented in Table 7, it can be concluded that the Moran's I index values for the period from 2013 to 2022 are consistently greater than 0, indicating a clustering effect in the level of digital economic advancement among neighboring cities in the region. This observation suggests that cities with both high and low levels of digital inclusive finance tend to exhibit spatial clustering. Moreover, all P-values are less than 0.05, which indicates statistically significant results, confirming the existence of a discernible pattern of spatial agglomeration in digital inclusive finance among cities in the region.

Analysis of regional innovation capacity measurement results

(1) Analysis of regional innovation capacity measurement results

Using the evaluation system outlined in Table 3, panel data from the 11 provinces and municipalities in the Yangtze River Economic Belt from 2013 to 2022 were collected and analyzed. During the measurement process, the data were first standardized, followed by the application of the entropy weight method to determine weights for the six assessing indicators. The calculated weights for each indicator are presented in Table 8. Subsequently, the comprehensive evaluation index for regional innovation capacity in these provinces and cities over the 2013-2022 period was computed using the scores and weights of the six indicators. The analysis is conducted separately for the upper, central, and lower parts of the region.

Table 8. Summary of weight calculation results using the entropy method

Indicator	Information Entropy (e)	Information utility Value	Weight coefficient
Informatization Level	0.9340	0.0660	15.82%
High-tech Industry Revenue Level	0.9547	0.0453	10.86%
Research Expenditure Intensity	0.9613	0.0387	9.28%
Research Personnel Scale	0.8952	0.1048	25.12%
Scientific Research Development Level	0.9417	0.0583	13.98%
Innovation Achievements	0.8960	0.1040	24.94%

Table 9. Regional innovation capability measurement results for upstream provinces and cities in the Yangtze River economic belt from 2013 to 2022

Year	Chongqing City	Sichuan Province	Yunnan Province	Guizhou Province
2013	0.1215	0.1636	0.0744	0.1190
2014	0.1388	0.1805	0.0845	0.1316
2015	0.1496	0.1871	0.1008	0.1238
2016	0.1612	0.2008	0.1030	0.1115
2017	0.1745	0.2141	0.1050	0.1211
2018	0.1767	0.2136	0.1024	0.1223
2019	0.1801	0.2099	0.1069	0.1086
2020	0.1917	0.2387	0.1221	0.1185
2021	0.2175	0.2534	0.1246	0.1140
2022	0.2320	0.2849	0.1323	0.1282

Based on the information from Table 9, the *RIC* of the upstream region of Chongqing, Sichuan, Yunnan, and Guizhou have shown an overall growth trend from 2013 to 2022. Among these regions, Chongqing has experienced particularly significant growth in *RIC*, rising from 0.1215 in 2013 to 0.2320 in 2022, with a notably rapid increase between 2018 and 2019. Sichuan also saw a steady increase in its *RIC*, reaching a score of 0.2849 in 2022. Despite some fluctuations in intermediate years, the overall growth trend remains evident. Yunnan and Guizhou also made progress in *RIC* over these nine years, though at a slower pace. These growth trends indicate the positive advancements made by the upstream region in the field of technological innovation.

According to Table 10, the *RIC* of Hunan, Hubei, and Jiangxi provinces has exhibited a steady upward trajectory over the years, highlighting the continuous advancements in technological innovation, talent development, and industrial transformation in the central part of the region.

Table 10. Regional innovation capability measurement results for central provinces and cities in the Yangtze River economic belt from 2013 to 2022

Year	Hunan Province	Hubei Province	Jiangxi Province
2013	0.1469	0.1632	0.1036
2014	0.1565	0.1769	0.0964
2015	0.1655	0.1896	0.1031
2016	0.1788	0.2076	0.1190
2017	0.1911	0.2016	0.1297
2018	0.2129	0.2245	0.1391
2019	0.2240	0.2352	0.1549
2020	0.2417	0.2634	0.1753
2021	0.2490	0.2800	0.1671
2022	0.2781	0.3108	0.1745

Specifically, Hunan's *RIC* experienced a notable increase from 0.1468 in 2013 to 0.2781 in 2022. Hubei's innovation capacity also displayed consistent growth, increasing from 0.1631 in 2013 to 0.3107 in 2022, reflecting the province's sustained focus on technological innovation. Although Jiangxi's *RIC* started from a relatively low base, its growth momentum is robust, increasing from 0.1036 in 2013 to 0.1744 in 2022, indicating positive progress in innovation capacity.

Additionally, the data reveals that Hubei stands out in the central areas in terms of *RIC*, not merely leading in the rate of growth but also achieving higher absolute values compared to the other two provinces. This can be attributed to Hubei's prominent role in central China, underpinned by a well-established technological innovation system and abundant technological resources.

Table 11. Regional innovation capability measurement results for downstream provinces and cities in the Yangtze River economic belt from 2013 to 2022

Year	Shanghai City	Anhui Province	Zhejiang Province	Jiangsu Province
2013	0.4026	0.1397	0.3318	0.3565
2014	0.4420	0.1639	0.3537	0.3816
2015	0.4662	0.1759	0.3725	0.3863
2016	0.5068	0.1878	0.4009	0.4160
2017	0.5340	0.1975	0.4268	0.4264
2018	0.5398	0.2047	0.4496	0.3984
2019	0.5858	0.2219	0.5030	0.4453
2020	0.6381	0.2548	0.5442	0.4545
2021	0.6753	0.2683	0.5621	0.4750
2022	0.7501	0.2981	0.6151	0.5104

From Table 11, the *RIC* scores of Shanghai, Anhui, Zhejiang, and Jiangsu in the downstream region showed an upward trend from 2013 to 2022.

Shanghai consistently maintained a high *RIC*, increasing from 0.4026 in 2013 to 0.7501 in 2022. Zhejiang's *RIC* followed with the second highest *RIC*, growing from 0.3318 in 2013 to 0.6151 in 2022, showing a significant increase. Jiangsu's *RIC* score, while lower than those of Shanghai and Zhejiang, also demonstrated a consistent growth, from 0.3565 in 2013 to 0.5104 in 2022. Anhui's regional innovation score was relatively low compared to other downstream provinces and cities, but it displayed a positive climbing inclination, from 0.1397 in 2013 to 0.2981 in 2022.

(2) Spatial autocorrelation analysis of regional innovation capability

Similar to the spatiotemporal analysis of the Digital Inclusive Finance index, the RIC index, derived using entropy-weighted method, is used as the analysis object. The Moran's I index for the provinces and cities of the region from 2013 to 2022 is calculated. Table 12 demonstrates detailed information.

Based on the results from Table 12, the Moran's I index for RIC shows an increasing trend from 2013 to 2020, with some fluctuations observed between 2020 and 2022. The Moran's I index for each year has exceeded the significance threshold test at the 0.05 level.

Table 12. Moran's I index for regional innovation capability of provinces and cities in the Yangtze River economic belt

Year	Moran's I	P-value
2013	0.6821	0.0011
2014	0.6815	0.0011
2015	0.6919	0.0009
2016	0.6924	0.0009
2017	0.7005	0.0008
2018	0.6890	0.0008
2019	0.7351	0.0005
2020	0.7327	0.0004
2021	0.7094	0.0006
2022	0.6962	0.0007

COUPLING COORDINATION DEGREE MEASUREMENT AND ANALYSIS OF DIGITAL INCLUSIVE FINANCE AND REGIONAL INNOVATION CAPABILITY IN THE YANGTZE RIVER ECONOMIC BELT

Coupling Coordination Degree Evaluation Model

The degree of interaction between two systems can be reflected by a coupling model, with the specific model as follows:

$$C = 2\frac{\sqrt{U_1U_2}}{U_1+U_2} \quad (7)$$

In the model, U_1 is the evaluation score of the *DIF* system, represented by the total index of *DIF* from Peking University's Digital Inclusive Finance Research Center. U_2 is the evaluation score of the regional innovation system, applying the entropy method according to the regional innovation evaluation index system in Table 3. C presents the degree of coupling between the two systems, with a range of 0 to 1. The closer C is to 1, the stronger the interaction between the two systems; conversely, the weaker the interaction.

The above coupling model can only reflect the intensity of the interaction between *DIF* and regional innovation but does not capture whether they are developing in coordination. If there is strong mutual constraint between the two systems, it can also be reflected by the C. Ths, based on the aforementioned model, a coupling coordination model is introduced. It can reflect whether there is a positive influence between *DIF* and regional innovation. The model is presented as follows:

$$T = \alpha U_1 + \beta U_2 \quad (8)$$

$$D = \sqrt{CT} \quad (9)$$

Where T represents the comprehensive coordination index, and D represents the coupling coordination degree. The variables U_1 and U_2 represent the system evaluation scores for *DIF* and regional innovation, respectively, while α and β are coefficients to be determined. Since *DIF* and regional innovation are considered equally important in this study, we set $\alpha = \beta$=0.5. For the convenience of subsequent research, this paper divides the coupling coordination degree into ten levels, as follows:

[0.0~0.1), Extremely Disordered

[0.1~0.2), Severely Disordered

[0.2~0.3), Moderately Disordered

[0.3~0.4), Mildly Disordered

[0.4~0.5), Near Disorder

[0.5~0.6), Barely Coordinated

[0.6~0.7), Primary Coordination

[0.7~0.8), Intermediate Coordination

[0.8~0.9), Good Coordination

[0.9~1.0], Excellent Coordination

Analysis of Coupling Coordination Degree Results

Coupling coordination degree of digital inclusive finance and regional innovation in the provinces and cities of the Yangtze River economic belt

Based on the upstream, midstream, and downstream regional classifications in Table 2, the coupling coordination degree of *DIF* and regional innovation in each region was analyzed. The analysis objects for the upper region are Chongqing, Sichuan, Yunnan, and Guizhou; for the central region, the analysis objects are Hubei, Hunan, and Jiangxi; and for the lower region, the analysis objects are Shanghai, Jiangsu, Zhejiang, and Anhui. Table 14 and Figure 1 show the variations in the coupling coordination level between Chengdu and Chongqing in the upstream region.

Table 13. Coupling coordination level changes in the upstream provinces and cities in the Yangtze River economic belt

Year	Chongqing City	Sichuan Province	Yunan Province	Guizhou Province
2013	0.501	0.522	0.216	0.446
2014	0.511	0.491	0.216	0.433
2015	0.484	0.477	0.21	0.356
2016	0.489	0.35	0.203	0.3
2017	0.49	0.326	0.188	0.296
2018	0.473	0.226	0.193	0.284
2019	0.575	0.574	0.491	0.497
2020	0.597	0.604	0.518	0.518
2021	0.635	0.638	0.538	0.533
2022	0.651	0.658	0.55	0.552

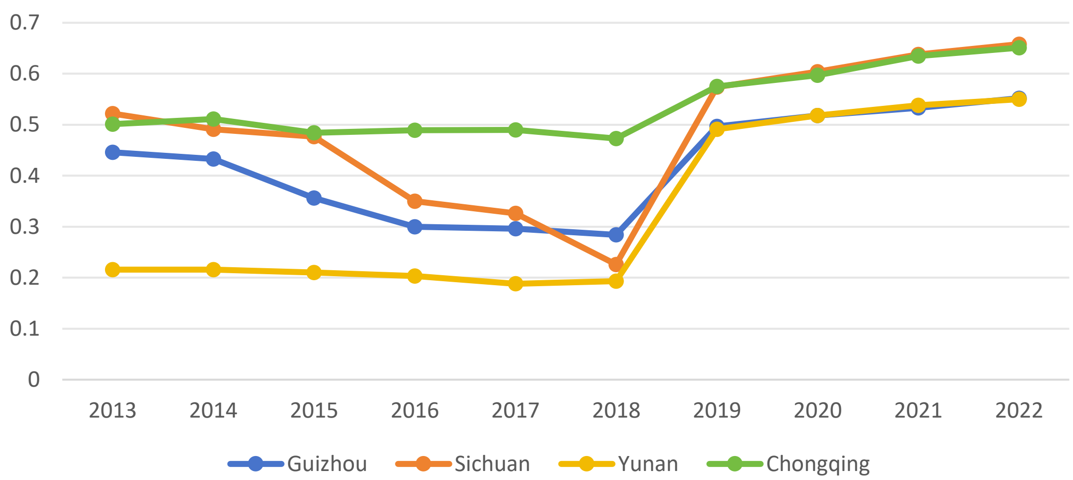

Figure 1. Change in coupling coordination level in the upstream provinces and cities of the Yangtze River economic belt

The data from 2013 to 2022 reveals that the coupling coordination levels between *DIF* and regional innovation in the upstream area, including Chongqing, Sichuan, Yunnan, and Guizhou, exhibited a gradual upward trend.

Notably, the coupling coordination levels of *DIF* and regional innovation in Chongqing and Sichuan showed significant improvement in recent years. Chongqing's coordination level increased from 0.501 in 2013 to 0.651 in 2022, while Sichuan's rose from 0.522 to 0.658, reflecting both high levels and positive growth. Although Yunnan and Guizhou started with relatively low coupling coordination levels, they also demonstrated steady growth recently.

Hunan, Hubei, and Jiangxi provinces in the central region are analyzed in the following section. Table 14 and Figure 2 illustrate the changes in the coupling coordination levels of these provinces from 2013 to 2022.

Table 14. Change in coupling coordination level in the midstream provinces and cities of the Yangtze River economic belt (2013-2022)

Year	Hunan Province	Hubei Province	Jiangxi Province
2013	0.688	0.542	0.483
2014	0.673	0.557	0.398
2015	0.653	0.534	0.308
2016	0.662	0.54	0.401
2017	0.673	0.485	0.41
2018	0.711	0.507	0.445
2019	0.661	0.613	0.566
2020	0.686	0.645	0.595
2021	0.706	0.677	0.607
2022	0.726	0.699	0.62

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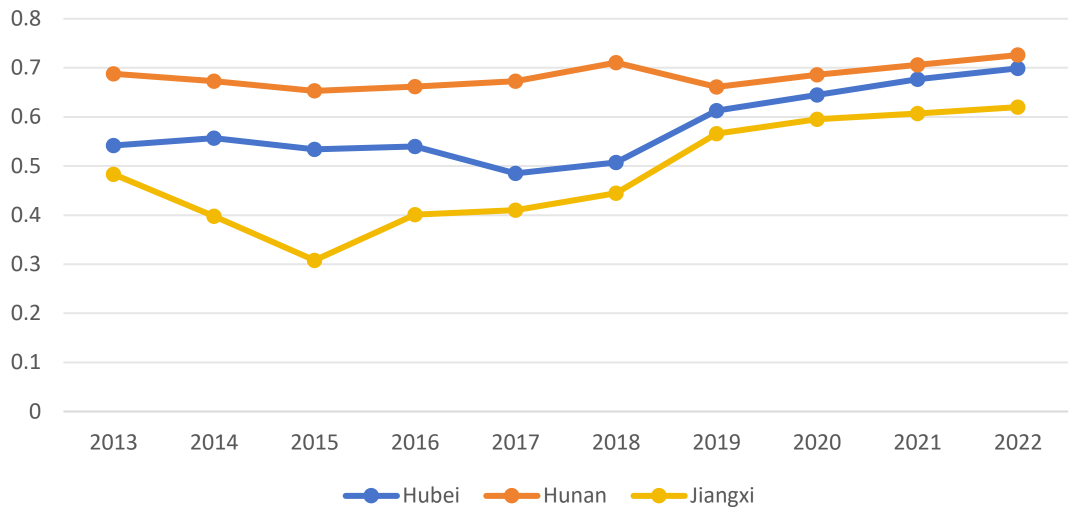

Figure 2. Coupling coordination level change trend in the provinces and cities of the midstream region of the Yangtze River economic belt

From the coupling coordination level measurement analysis of midstream region in Table 14 and Figure 2, it is observed that the overall coupling coordination level has shown a stable upward trend from 2013 to 2022. Specifically, Hunan Province's coupling coordination level has consistently remained at a relatively high level, increasing from 0.688 in 2013 to 0.726 in 2022. Hubei Province's coupling coordination level also shows a sustained upward movement, growing from 0.542 in 2013 to 0.699 in 2022, with a significant increase. Although Jiangxi Province had a relatively low coupling coordination level in the initial stage, it has demonstrated a consistent upward trend in recent years, from 0.483 in 2013 to 0.62 in 2022.

The analysis objects for the downstream region are Shanghai, Anhui, Zhejiang, and Jiangsu provinces. Table 15 and Figure 3 show the coupling coordination level changes in the provinces and cities of the downstream part in 2013-2022.

Table 15. Coupling coordination level change in the provinces and cities of the downstream region of the Yangtze River economic belt

Year	Shanghai City	Anhui Province	Zhejiang Province	Jiangsu Province
2013	0.771	0.54	0.899	0.304
2014	0.748	0.549	0.889	0.301
2015	0.751	0.531	0.89	0.297
2016	0.72	0.529	0.878	0.296
2017	0.705	0.505	0.876	0.294
2018	0.682	0.509	0.892	0.386
2019	0.765	0.608	0.794	0.693
2020	0.798	0.644	0.823	0.712
2021	0.835	0.674	0.849	0.747
2022	0.864	0.698	0.872	0.755

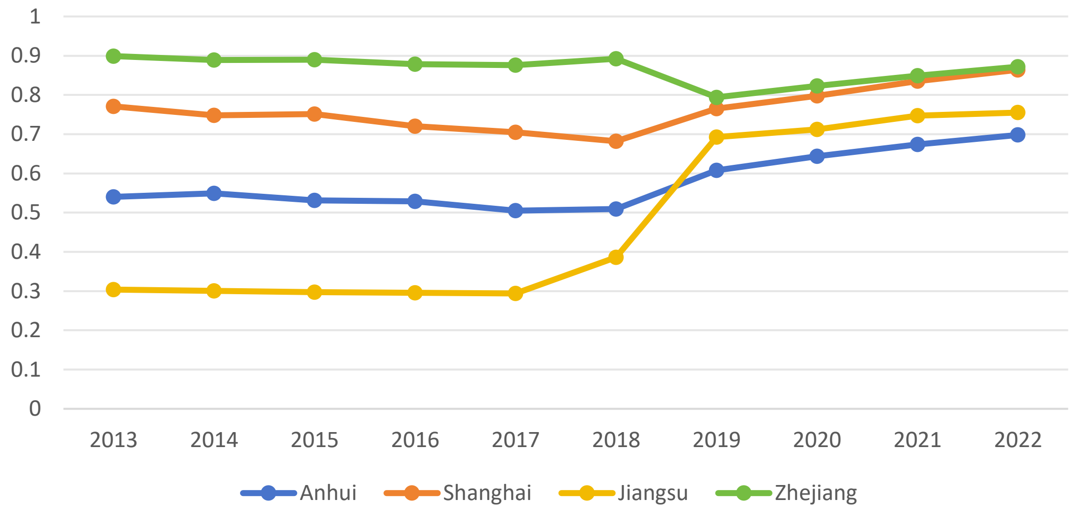

Figure 3. Coupling coordination level change trend in the downstream provinces and cities of the Yangtze River economic belt

From 2013-2022, the coupling coordination degree of the center in the downstream region showed some fluctuations but generally exhibited an upward trend, especially after 2019, when this trend became more evident.

As the core city in the downstream region, Shanghai maintained a relatively high coupling coordination level, increasing from 0.771 in 2013 to 0.864 in 2022. Zhejiang's coupling coordination level fluctuated, changing from 0.899 in 2013 to 0.872 in 2022. Jiangsu and Anhui also saw significant improvements in their coupling coordination levels in recent years. Jiangsu's level rose sharply from 0.304 in 2013 to 0.755 in 2022, showing a substantial increase. Anhui's coordination level increased from 0.54 in 2013 to 0.698 in 2022.

Spatiotemporal evolution of the coupling coordination degree between digital inclusive finance and regional innovation capability in the Yangtze River economic belt

Based on the results calculated earlier, the development levels of *DFI* and the coupling coordination degrees of *RIC* in the 11 provinces and cities (2013-2022) were analyzed. The Moran's I index was calculated to examine the spatio-temporal evolution of the coupling coordination level in these provinces and cities.

Table 16. Moran's I index of coupling coordination level in provinces and cities in the Yangtze River economic belt

Year	Moran's I	P-Value
2013	-0.0178	0.3371
2014	-0.0235	0.3491
2015	0.0097	0.2914
2016	0.1513	0.1052
2017	0.3313	0.0133
2018	0.3224	0.0172
2019	0.5733	0.0004
2020	0.5862	0.0003
2021	0.5643	0.0003
2022	0.5500	0.0006

According to Table 16, from 2013 to 2014, the Moran's I index for the provinces and cities in the region was negative. However, from 2013 to 2020, it exhibited an increasing trend.

From 2015 to 2022, the Moran's I index of the coupling coordination degree was positive, with fluctuations in some years. Overall, it was increasing. The P-value test revealed that the Moran's I index was not significant from 2013 to 2016, but its significance gradually increased over the years. After 2017, the coupling coordination level demonstrated a clear positive correlation.

MECHANISM ANALYSIS OF THE COUPLING COORDINATION DEGREE BETWEEN DIGITAL INCLUSIVE FINANCE AND REGIONAL INNOVATION CAPABILITY IN THE YANGTZE RIVER ECONOMIC BELT

The previous study shows that the coupling coordination degree between the *DIF* development level and *RIC* in the provinces and cities of the region exhibits a clear spatial clustering and spatial correlation effect. For each province or city, its coupling coordination level is influenced not only by the elements it possesses but also by the coupling coordination levels of other places.

Building on the research in Chapter 3, this chapter selects the potential influencing factors of the coupling coordination degree between *DIF* and *RIC* in the provinces and cities of the region, and analyzes the mechanism and path of their impact based on the spatial Autoregressive model (SAR).

Model construction and variable selection

Model construction

This study confirms the spatial correlation between *DIF* and *RIC* coupling coordination degree. Ignoring spatial effects could lead to estimation errors. Therefore, this study constructs a Spatial Autoregressive Model (SAR) for fitting, and uses spatial lag model estimation grounded in related tests. The panel data are selected for the study. The coupling coordination degree is adopted as the dependent variable, while the potential influencing factors are adopted as independent variables. To lessen the effects of heteroscedasticity on model estimation, the logarithm of the variables on both sides of the model formula is taken. The model is as follows:

$$\begin{aligned} Ln(Y) = a + \rho W Ln(\mathrm{Y}) + \beta_1 \ln(X_1) + \beta_2 \ln(X_2) + \beta_3 \ln(X_3) + \beta_4 \ln(X_4) + \beta_5 \ln(X_5) \\ + \beta_6 \ln(X_6) + \varepsilon \end{aligned} \tag{10}$$

In the model, ε symbolizes the random error term, W is the 11x11 spatial weight matrix, and ρ is the coefficient reflecting the impact of neighboring regions' observed value errors on the local area.

Variable selection

(1) Dependent variable selection

In this study, the coupling coordination degree between *DIF* and *RIC* is chosen as the dependent variable.

(2) Independent variable selection

The coupling coordination degree of *DIF* and *RIC* is influenced by multiple factors. These factors not only include indicators related to technology and education, such as the level of information technology development, number of patent applications, and technology expenditure, but also economic structure indicators, such as the share of the tertiary industry and per capita GDP. Based on existing research, this study identifies six main factors influencing the coupling coordination degree of *DIF* and *RIC* in the region: economic foundation, foreign trade level, education level, technological support intensity, information development level, and industrial structure level.

Economic Development Level: There are three main ways to measure a region's economic development level: 1) by per capita GDP; 2) by the annual growth rate of regional GDP; 3) by the total regional GDP. In this study, following the approach of Tao Yi et al. (2023), per capita GDP is used as the measure for economic development.

Foreign Trade Level: International trade enhances innovation exchange and promotes technological innovation. This study uses per capita import-export value to measure the foreign trade level of a region.

Education Level: Higher education is a key aspect of cultivating innovative talent. The development of higher education reflects its innovation capacity to some extent. This research utilizes the number of students enrolled in ordinary undergraduate and college programs to indicate how developed the higher education is.

Technological Support Intensity: Fiscal support is crucial for technological innovation. This study utilizes the ratio of scientific and technological fiscal expenditure to GDP as an indicator of the region's investment in innovation.

Information Development Level: Information development is a driver of innovation. This study uses the proportion of mobile internet users to measure a region's information development level.

Industrial Structure Level: Industrial structure can stimulate both the development of digital inclusive finance and high-tech industries. Thus, this research employs the proportion of the tertiary sector within GDP as an indicator of the industrial structure's advancement.

In summary, the study establishes corresponding evaluation indicators for the six influencing factors, and the main factors influencing the coupling coordination degree are detailed in Table 17.

Table 17. Influencing factors of coupling coordination degree

Indicator	Explanatory Variable
Economic Foundation	Per capita GDP (Yuan/person)
Education Level	Number of students enrolled in undergraduate and college programs (persons)
Technology Support Intensity	Technological expenditure/GDP (%)
Information Development Level	Proportion of mobile internet users (%)
Industrial Structure Level	Proportion of the tertiary industry in GDP (%)
Foreign Trade Level	Total import-export trade / GDP (%)

Analysis of benchmark results

Based on the modeling analysis results in Table 18, the economic foundation, education level, information development level, and foreign trade level show a positive correlation with the coupling coordination degree of *DIF* and *RIC*. Among these, the economic foundation has the highest positive impact on the coupling coordination degree, with a value of 0.3257.

Table 18. Empirical results of SAR model influencing factors

Indicator	Estimated Value	P-value
Residual Term	0.1432	0.0032
Economic Foundation	0.3257	0.0054
Education Level	0.1519	0.0336
Technological Support	-0.0079	0.8564
Information Development	0.1441	0.0450
Industrial Structure	-0.1340	0.2350
Foreign Trade Level	0.1335	0.0471
ρ	0.6294	<2.22e-16

Space Lag Model: four explanatory variables are significant, among which economic foundation, education level, information development level, and foreign trade level passed the significance test at the 0.05 level. Technological support and industrial structure levels did not pass. ρ (rho) represents the influence of the neighboring area's explanatory variable error on the target observation in this region, with a value of 0.6294, indicating that the coupling coordination degree shows a strong spatial agglomeration effect.

Robustness test

The robustness test employs two means:

(1) Add 3 control variables and observe the changes in the model;

(2) Change the method of calculating spatial weights, using the KNN (K-Nearest Neighbors) method to calculate the spatial weight matrix and establish the SAR model.

Table 19. Control variables and definitions

Control Variable	Variable Definition
Industrial Structure Advancement	Tertiary Industry Value Added / Secondary Industry Value Added (%)
Enterprise R&D Scale	Number of R&D projects in industrial enterprises above designated size
Enterprise Informatization Level	Number of websites per 100 enterprises

The SAR model is established using data with the addition of 3 control variables and changes to the spatial weight coefficient matrix. As shown in Table 19, the details of the two robustness test models are compared with the original model in Table 20.

Table 20. Robustness test results

Indicator	Adding Control Variables		Changing Spatial Weight Matrix	
	Estimated Value	P-value	Estimated Value	P-value
Residual Term	0.2606	1.755e-07	0.2541	4.024e-08
Economic Foundation	0.3429	0.0051	0.4755	0.0001
Education Level	0.1895	0.0006	0.1449	0.0097
Technology Support	-0.0959	0.3767	-0.1683	0.1271
Information Development	0.0860	0.0481	0.0970	0.0433
Industrial Structure	-0.0307	0.9006	-0.1216	0.6309
Foreign Trade Level	0.1590	0.0455	0.1168	0.0396
ρ	0.695	<2.22e-16	0.6950	< 2.22e-16
Industrial Structure Advancement	-0.1148	0.6083	-	-
R&D Expenditure	-0.1228	0.1107	-	-
Technology Innovation Potential	-0.1359	0.1273	-	-

According to the robustness test results in Table 20, after control variables have been added, and the method of calculating the spatial weight matrix has been changed, the newly established SAR model has the same signs for the coefficients as the original SAR model, and the significance levels are consistent. The regression results do not differ substantially from the baseline regression conclusions, proving that the model established has good robustness.

Heterogeneity analysis

Table 21. Heterogeneity analysis results

Indicator	Regional Division					
	Upstream Region		Midstream Region		Downstream Region	
	Estimated Value	P-value	Estimated Value	P-value	Estimated value	P-value
Residual Term	0.6117	3.359e-06	0.3649	0.0678	0.2649	0.0815
Economic Foundation	1.3092	0.0055	0.0112	0.9795	0.7943	0.0106
Education Level	0.1277	0.0708	0.3207	0.1899	-0.3734	0.0197
Technology Support	0.3066	0.0212	0.3540	0.0089	0.3409	0.0421
Information Development	0.1157	0.7218	0.6526	0.1822	-0.093	0.2559
Industrial Structure	-1.0757	0.0001	-0.2199	0.6889	-1.0101	0.0130
Foreign Trade Level	0.3500	0.3951	-0.6722	0.5235	-0.1053	0.4150
ρ	0.2692	0.0728	0.01523	0.6761	0.0670	0.0066

Considering the significant regional differences in the spatiotemporal distribution of provinces and cities along the Yangtze River Economic Belt, this study divides the region into three parts: the upper, central, and lower region. The analysis investigates the causes of the consistency in the coupling coordination degree of *DIF* and *RIC* across the region. The regression results are shown in Table 21.

According to heterogeneity analysis in Table 21, it is observed that in the upstream regions, the economic basis and education level positively influence the coupling coordination degree. However, the relatively high P-value for education level suggests its impact is not significant. This may be attributed to the uneven distribution of educational resources and the need for improvement in educational quality in these areas, which limits the role of education in enhancing regional innovation capacity.

Technological support, on the contrary, shows a positive and significant impact on the coupling coordination degree, as indicated by a significant P-value. While both the information development level and foreign trade level have positive coefficients, their P-values exceed the critical value, suggesting these factors do not largely influence the coupling coordination degree in the upstream region. This could be due to the relatively low levels of informatization and foreign trade openness in these areas.

The industrial structure level, however, negatively influences the coupling coordination degree, with a P-value less than 0.05, indicating its significant influence.

In the midstream region, the education level also shows a positive effect on the coupling coordination degree, though the impact is not statistically significant, as reflected by the P-value. This may be due to issues in the allocation of educational resources and policy implementation, which have prevented education from fully driving innovation. The impact of technological support, however, is both positive and statistically significant.

In the downstream region, the economic foundation positively influences the coupling coordination degree, with a significant P-value indicating its importance. This can likely be attributed to the region's mature economy and its ongoing optimization and transformation of industrial structures. Technological support in this region also demonstrates a positive and significant impact, suggesting considerable progress in technological application, which has substantially enhanced regional innovation capacity.

CONCLUSIONS AND RECOMMENDATIONS

This paper analyzes panel data from 41 cities across 11 provinces (including municipalities) within the Yangtze River Economic Belt, spanning from 2013 to 2022. The study employs the Digital Inclusive Finance Index (*DIF*) developed by the Peking University Digital Finance Center to gauge the level of *DIF* development in the region. It further establishes a systematic evaluation for Regional Innovation Capacity (*RIC*) and uses the entropy method to calculate the *RIC* within the region. The coupling coordination degree between *DIF* and *RIC* is assessed using a coupling coordination model, and the relationship between the two is examined through the Spatial Autoregressive Model (SAR). Therefore, the following conclusions and recommendations emerge:

Research Conclusions

(1) Development status of digital inclusive finance and regional innovation capacity in the Yangtze River economic belt.

The research shows that both digital *DIF* and *RIC* in the region are on an overall upward trajectory. However, the development levels differ significantly across cities and regions. Some areas, such as Shanghai, Jiangsu, and Zhejiang, started with relatively high levels of *DIF* and *RIC*, while others began from lower points but have demonstrated rapid growth.

(2) Coupling Coordination Status and Influence Mechanism Between Digital Inclusive Finance and Regional Innovation Capacity.

The study reveals a general upward trend in the coupling coordination between *DIF* and *RIC* across most regions. However, the majority of provinces are still classified within the "barely coordinated" or "primary coordination" stages. Only Shanghai, Jiangsu, Zhejiang, and Hunan have achieved intermediate or good coordination levels. Factors such as economic foundation, education level, information development level, and foreign trade positively influence the coupling coordination between *DIF* and *RIC*. In contrast, technological support and industrial structure levels have a negative impact on their coordination. Additionally, the coupling coordination degree exhibits strong spatial agglomeration effects.

(3) Heterogeneity Analysis.

The heterogeneity analysis confirms that the impacts of various factors on the coupling coordination between *DIF* and *RIC* align with the overall findings. However, there are notable regional differences across the upstream, midstream, and downstream areas, affecting the degree of influence of each factor.

Policy Recommendations

(1) Enhance the Development of Digital Inclusive Finance and Improve Regional Innovation Capacity.

Future *DIF* development should be tailored to local conditions, focusing on differentiated, executable policies. Regions should prioritize quality development by accelerating the construction of digital infrastructure, expanding the scope and digitalization of *DIF* services, and aligning these with the needs of regional innovation capacity. Additional investments in regional innovation activities, improvements in educational and research environments, and enhanced support for universities and research institutions will help improve technological efficiency.

(2) Increase the Coupling Coordination Degree Between Digital Inclusive Finance and Regional Innovation Capacity in the Yangtze River Economic Belt.

The coupling coordination degree remains low in many cities of the region. To address this, regions must focus on strengthening economic infrastructure, bolstering support for education and research, accelerating informatization development, improving information infrastructure, enhancing openness, and boosting foreign trade to foster better coupling coordination between *DIF* and *RIC*.

(3) Promote Coordinated Development Between Digital Inclusive Finance and Regional Innovation Capacity Across Regions.

Significant disparities exist in the coupling coordination of *DIF* and *RIC* across all regions of the Yangtze River Economic Belt. Policy support and resource allocation should be more focused on the upper and central regions, which are currently weaker.

These regions should leverage their unique advantages to accelerate the development of coupling coordination between *DIF* and *RIC*.

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