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The Development of Digital Finance and Regional Green Innovation Coupling and Coordination Analysis

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Abstract: The coordinated developmental nature between regions is explored from two perspectives: the degree of coupled and coordinated development between digital finance and regional green innovation and the spatial characteristics. Firstly, the coupling coordination model is used to calculate the degree of development level of two-way promotion between the two systems, furthermore, the Moran index is used to analyze the spatial correlation of the coupling coordination degree values, and finally, the influence of each digital finance and green innovation influencing factor of neighboring cities on the coupling agglomeration effect is studied through the spatial error model. Through the empirical analysis, it is found that the coordination degree of digital finance development and green innovation degree in the region is good, and the two can show the trend of coordinated development on the whole, and the coordination degree of digital finance development and green innovation degree in the Yangtze River Economic Zone has the characteristics of more obvious spatial non-equilibrium in the studied interval, and improving the coordination value of the provinces on the verge of disorder is the key to improve the coordinated development of digital finance and green innovation in the Yangtze River Economic Zone. The key to improve the coordinated development of digital finance and green innovation in the Yangtze River Economic Zone is to improve the coordination value of the endangered provinces. From the perspective of global autocorrelation, it can be learned that the coupling coordination degree presents significant characteristics in spatial agglomeration, and the local Moran index indicates that the local agglomeration effect in the Yangtze River Economic Belt mainly presents "high-high", "low-low", and "high-low" types. "Finally, the regression results obtained from the spatial error model show that the five indicators of digital financial usage depth, economic growth rate, green total factor productivity, foreign direct investment, and digital financial digitization all play a positive role in promoting the improvement of the regional coupling agglomeration effect.

Keywords: Coupling coordination, Moran index, Digital finance, Green innovation, Spatial error model.

1. Introduction

Faced with the increasingly serious global warming, green innovation to improve the resource cycle will play a crucial role in alleviating this situation. At present, influenced by the economic structure and energy structure, and accompanied by the intensification of the great uncertainty caused by the new crown pneumonia epidemic on economic and social development, the comprehensive promotion of the green transformation of the economy still needs to make strenuous efforts. To this end, it is necessary to strengthen the construction of green development standard system, accelerate the development of green technology innovation, promote the high level of ecological environment protection, and create new momentum for green development. Combined with China's "double carbon" target strategy, this paper continues to dig down in the level of science and technology innovation and focuses on the green innovation system. Through the analysis of the green innovation system, we clarify the coupling development relationship between green innovation and digital finance, coordinate the relationship between financial development and environmental stability in the transformation of digital finance, and give This paper is based on the "Opinions" of the Chinese government. This paper selects digital finance and green innovation as the research content of this paper based on the requirements and rules in the "Opinions", and selects the panel data of 11 provinces and cities in Yangtze River Economic Zone from 2011 to 2020 as the research object of this paper from the perspective of coupling agglomeration effect. Through the mechanism analysis and empirical measurement of the development level of digital finance and the performance of regional green innovation, we explore the interaction between the two in the Yangtze River Economic Belt, and provide a reference for the coordinated development of digital finance and green innovation in the Yangtze River Economic Belt and other urban clusters in China, so as to promote the construction of a new double-cycle development pattern.

The important role of regional digital inclusive finance for the development of local green innovation has been the focus and hot issue of domestic scholars' research, and many scholars have conducted theoretical and practical research on this issue from different perspectives of Chinese cities, regional innovation and enterprise technology, and the research results are rich.

From the perspective of Chinese cities, Liang Bang et al. (2019) concluded that the development of digital inclusive finance and its breadth of coverage, depth of use and degree of digital support services have a significant positive impact on technological innovation [1]; Tang Wenjin et al. (2019), starting from the relationship between the development of digital inclusive finance and industrial structure upgrading, found that there is a non-linear relationship between the depth of use and digitalization of digital inclusive finance and industrial structure upgrading. non-linear relationship and the non-linear effect of digital inclusive finance development on industrial structure upgrading in different regions is heterogeneous; digital inclusive finance has become the key to break through the dilemma of urban green innovation efficiency enhancement [2]. From the perspective of the

impact of digital inclusive finance on green innovation efficiency, Zhang Jefei et al. (2022) found that although digital inclusive finance has a positive impact on enhancing urban green innovation efficiency, it has a siphon effect on green innovation efficiency in neighboring cities, and there is a double threshold effect of digital inclusive finance on green innovation efficiency in neighboring cities [3]. From the perspective of regional innovation, Wang Lixiao et al. (2022) found that digital finance has a positive impact on green innovation, and the empowerment effect is more obvious in the eastern region and in the long term [4]; Ge Shisai et al. (2022) concluded that the influence of industrial structure on green innovation performance is more significant, and promoting the optimization and upgrading of industrial structure is an important way to enhance green innovation performance in the region, and enhancing inter-regional information accessibility can The paper argues that green innovation is an important link between green economics and green innovation.

This paper argues that green innovation is a product of the combination of green economics and innovation systematics, and the innovative technological achievements that can improve green economic benefits are produced when economic activities are carried out. From the perspective of enterprise technological innovation, Wang B. et al. (2022) and others found that the driving effect of digital finance on green technological innovation was more pronounced in state-owned enterprises and heavily polluting enterprises relative to non-state-owned enterprises and non-heavily polluting enterprises [6].

The above academic results provide solid theoretical support and methodological inspiration for the theoretical and practical research of this paper, but it is not difficult to find that the following perspectives are still worth exploring in the existing research.

1. The coupling mechanism between green innovation and digital finance has not been truly established

The theoretical mechanism of the interaction between green innovation and digital finance is not yet clear, limited by the cognitive development of new things. Although there are a large number of studies on green innovation and digital finance, neither of them has formed a unified definition due to different research perspectives and standards, and the index systems of green innovation and digital finance differ at the regional level. Secondly, most researchers focus on the one-way influence of both green innovation and digital finance on each other, for example, on the study of the influence of digital finance development on corporate green innovation, and few researchers focus on the two-way influence and coupling development mechanism between green innovation and digital finance.

2. Lack of research on the measurement of spatial and temporal effects of green innovation and digital finance

When examining the relationship between digital finance and innovation development or green economic development, most studies discuss from one direction, examining the one-way effect of digital finance on innovation or green development and emphasizing the development advantages of digital finance; few studies start from the perspective of spatio-temporal effect measurement and use spatio-temporal development theory to study the spatio-temporal development relationship between digital finance and green innovation. From the perspective of system theory, digital finance as a social product from digital technology innovation to development and application, its system itself operates dynamically, while the green innovation system is also a dynamic system continuously developed and improved by the government and the market. What kind of spatio-temporal development mechanism the two systems would have under the same social market environment, and how much the two would develop jointly, are of great value to the current study.

By drawing on the conclusions of previous studies, this paper argues that digital finance refers to a new generation of financial service model that combines the Internet and information technology means with the traditional financial service industry. With digital technology as the driving core and modern information technology as the carrier, through the development of digital industry and integration with traditional industry, the developed economic form of traditional economic model is continuously updated and reconstructed by reducing the circuitous and complex economic activities in the traditional economic model, and the consumption of various production factors therein, and the interactive relationship between digital finance and regional green innovation and the factors affecting this relationship are studied. It is beneficial to improve digital finance in the region, enhance the efficiency of financial resource allocation, and better play the role of finance in promoting economic growth. Therefore, this paper constructs coupled coordination evaluation indexes, integrates Stata, GeoDa, ArcGIS and other software to study the spatial and temporal evolution trends of the level of coordinated development of digital finance and green innovation in the Yangtze River Economic Belt, and analyzes the factors affecting the level of coordination, with a view to improving the coordinated development of provinces and cities in the Yangtze River Economic Belt. The possible contribution of this paper to the national policy of promoting the development of domestic recycling is reflected in the following two aspects: from the perspective of the aggregation effect of the coordinated development of "digital finance-green innovation", we use coupled coordination models and spatial autocorrelation analysis to analyze the coordinated development of digital finance and green innovation in different regions of the Yangtze River Economic Belt. The spatial regression model is used to measure the factors affecting the coupling and coordination of digital finance and green innovation in the Yangtze River Economic Zone. The policy of promoting the development of a large domestic cycle is combined with the initial formation of a green low-carbon cycle economic system by 2025, and the target of significantly improving energy use efficiency in key industries.

2. Theoretical Analysis

According to Wang Yang et al. (2022), it was found that: the coupling coordination between digital inclusive finance and innovation development in most regions of China is at a steady increase, but the overall coupling level is still low, and most regions are between low and moderate coupling [7]. Zou Crescent et al. (2021) constructed a science and technology innovation evaluation system including government, enterprises, and research institutes, and used a spatial joint cubic equation model to conduct an empirical study on the interaction effects between digital finance and science and technology innovation [8]. The results show that the coupling coordination between digital finance and science and technology innovation in China shows the distribution characteristics of high in the east and low in the west, high in

the south and low in the north, but with the transformation and upgrading of economic structure, the coupling coordination between the two develops from a low degree to a benign resonance. Therefore, this paper proposes the following hypothesis: Hypothesis 1: The overall development of digital inclusive finance and green innovation shows low coupling and high coordination, and does not reach the trend of benign resonance.

According to Guo Feng of Digital Finance Research Center of Peking University, it is found that the growth of the depth of digital finance usage has become an important driver of the growth of digital inclusive finance index, which is in contrast to the index of the first period 2011-2015, proving that China's digital inclusive finance business has gone through the era of rough enclosure and entered a new stage of deep expansion. Meanwhile, Zhang Xiaofeng et al. (2022) analyzed the interaction between digital inclusive finance and regional economic development by establishing an individual fixed-effects model and found that the utilization rate index significantly promoted regional economic growth in the west and northeast, and the digitalization index significantly promoted regional economic growth in the east and central regions [9]. Yin Yue et al. (2022) concluded that digital finance, breadth of coverage, depth of usage, and digitalization contribute to total factor productivity by increasing the degree of industrial diversification and agglomeration through systematic GMM model and recursive effect model [10]. Therefore, the depth of use of digital finance, which represents the actual use of digital inclusive finance and the active degree of use of each business segment, and the degree of digitalization of inclusive finance, which indicates the ease of access to digital inclusive financial services and the cost of loan interest rates, are the main sources of promoting the development of digital inclusive finance. Based on this, this paper proposes: Hypothesis 2: The increase in the depth of digital financial usage as well as the degree of digitalization of inclusive finance will facilitate the coordinated development of provinces and cities in the region.

The deep integration of digitalization and greening is the driving force for the current high-quality economic development [11], and Yu Jintao et al. (2022) proposed that digital finance not only has a positive promoting effect on the green total factor productivity of the city, but also radiates the green total factor productivity of neighboring cities [12]. Jiao Ranqing (2022) found that the development of digital finance promotes green total factor productivity from the perspective of macroeconomic factors, and this enhancement effect has obvious heterogeneity in geographic location and city rank, i.e., the effect is stronger in cities in the eastern region and key cities than in cities in other regions and cities with lower administrative rank [13]. Therefore, this paper proposes: Hypothesis 3: The improvement of green total factor productivity can promote the improvement of the degree of coupled and coordinated development between the two systems in each province and city in the region.

Based on the theoretical analysis, the presentation of the research model of coupled and coordinated analysis of digital finance and regional green innovation development is carried out.

3. Model Building

(i) Coupling coordination model

Coupling degree originates from physics and is used to measure the interdependence between two systems, describing the intensity of interaction (or related influence) between two systems or two elements. Coordination degree, on the other hand, refers to the degree of benign interaction between two systems or two elements, which reflects the sustainability of the development state and the relevance of benign interaction, and can characterize whether the systems or elements promote each other at a high level or constrain each other at a low level. "The deepening of digital financial inclusion can reduce unnecessary energy loss in traditional finance and improve the level of green innovation development, while the improvement of green innovation technology will also promote the development of digital finance, forming a coupling between the two [14]. A coupled system of mutual influence and interdependence. In this paper, the strength of the association between the mutual influence and interaction of green innovation in digital finance is defined as the coupling degree, and the interaction between the coordinated development of both is defined as the coordination degree.

This paper draws on the two-system coupling evaluation model of Huo Ying [15], where C denotes the coupling degree; F and E denote the comprehensive evaluation functions of digital finance and green innovation development, respectively; k is the adjustment coefficient, and k=2 in this study.

$$C = \{F \times E/[(F+E)/2]^2\}^k$$

$$F = E = \sum_{i,j=1}^{n} W_{ij} \times X_{ij}$$

In order to better reflect the degree of development level of two-way promotion between two systems or two elements, this paper introduces the calculation method of coupling coordination degree, which is judged based on the existing research standards. Where: D denotes the degree of coordination; S is the comprehensive development index of digital finance and green innovation; a,b are coefficients to be determined, in this paper, we regard the two systems as equally important, so we set the adjustment coefficient a=b=0.5.

$$D = \sqrt{C \times S}$$

$$S = \sqrt{aF + bE}$$

(ii) Spatial correlation test model

Before spatial modeling, the variables need to be analyzed for spatial correlation. Spatial heterogeneity reflects the instability of economic activity relationships among spatial units, and there are non-negligible individual differences among enterprises, universities, research institutions and other subjects of regional innovation in digital economy development and green innovation activities, and such differences will likely lead to interdependent phenomena or local club effects of variables in geographic space. Moran index is a common method for analyzing spatial correlation.

1. Brief description of the measurement method

The magnitude of the global Moran index reflects the degree of aggregation and dispersion of indicators in the global context.

Moran I (global Moran index) is defined as follows:

$$\text{Moran I} = \frac{\sum_{i=1}^{n}\sum_{i=1}^{n} w_{ij}(y_i - \bar{y})(y_j - \bar{y})}{s^2 \sum_{i=1}^{n}\sum_{i=1}^{n} w_{ij}}$$

in the formulas$^2 = \frac{1}{n}\sum_{i=1}^{n}(y_j - \bar{y}), \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$, yi is the selected index value of the first place .The observed value, n is the total number of spatial units (11 in this paper), w_{ij} is the binary spatial weight matrix, reflecting the spatial regional proximity of the n spatial units, to determine the size of the weight of the units in space.

$$w = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1n} \\ w_{21} & w_{22} & \cdots & w_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ w_{n1} & w_{n2} & \cdots & w_{nn} \end{bmatrix}$$

In general, depending on whether the two units are adjacent or not, the value of w_{ij} is:

$$w_{ij} = \begin{cases} 1(\text{Adjacent}) \\ 0\ (\text{Non-adjacent}) \end{cases}$$

In the formula: and Moran I is the product sum of the observations in each region, which takes values in the range [-1,1].

After the global Moran index is significant, the local Moran index should be calculated. The local Moran index can reflect the specific area where the index is significant and determine the location where the index is significant; when the global Moran index is not significant or the index is zero, the local Moran index can reflect whether the index has an aggregation or dispersion effect in the local space.

2. Calculation process and results

The global Moran calculation generally uses the Queen neighbor method, which requires two regions to have common boundaries or nodes in order to be counted as proximity elements; according to the empirical formula, if the calculation results are required to have good confidence, at least 30 spatial units are needed to ensure that each unit has enough proximity elements. In this paper, there are 11 units in the study area, and the data have a certain skewness, so here we increase the proximity elements of each unit by increasing the accuracy threshold of the calculation to increase the credibility of the analysis results.

(iii) Spatial error model

The spatial error model focuses on the degree of influence of the respective variables (influencing factors of digital finance and green innovation) of neighboring cities on the dependent variable (the degree of coordination of coupling digital finance and green innovation) in the region. The model is set up in the following form:

$$\ln C_{it} = \beta_0 + \lambda W \varepsilon_{it} + \beta_1 \ln\text{Usage\_depth}_{it} + \beta_2\, \text{GDPGRO}_{it} + \beta_3 \text{GTFP}_{it} + \beta_4 \ln\text{GREDIT}_{it} + \beta_5 \ln\text{Digit\_level}_{it} + u_{it}$$

where: Usage_depth, GDPGRO, GTFP, Gredit, Digit_level denote the depth of digital finance usage, economic growth rate, green total factor productivity, foreign direct investment, and digital finance digitization level, respectively, where GDPGRO and GTFP are ratio values or percentile values, so they are not taken as logarithms; W is the spatial weight matrix; μ is the the random error of normal distribution; β0 is the constant term, β1~β5 are the regression coefficients of each variable; λ is the spatial error coefficient, and when λ is significantly non-zero, it indicates the direction and degree of influence of the independent variables in adjacent regions on the dependent variable in the current region.

4. Analysis of Empirical Results

From the perspective of global autocorrelation of the Yangtze River Economic Belt, it can be learned that the coupling coordination shows significant characteristics in spatial agglomeration, where the Moran index shows a fluctuation around -0.2 first, and then changes to 0.1621 by 2014, and shows an upward trend from 2014 to 2018, from 0.1621 in 2014 to 0.4651 in 2018, indicating that The spatial clustering effect of coordinated development of digital finance and green innovation in the Yangtze River Economic Zone between 2014 and 2018 has been increasing, and the Moran index becomes negative again after 2018, with the Moran index value of -0.2160 in 2019 and -0.2270 in 2020, indicating that the spatial clustering effect characteristics of these two years compared to the coordinated value in 2014 show a weakening shape. Meanwhile, for the analysis of all autocorrelations in the Yangtze River Economic Zone, the p-values pass the significance test at 1% or 5% level in both the weight matrix and the geographic distance matrix, while the z-values of the study area are all greater than 1.96, indicating that the global spatial effects pass the test.

Table 1. Global Moran index calculation results.

Year	Adjacency matrix			Geographical distance matrix		
	Moran's I	Z-value	P-value	Moran's I	Z-value	P-value
2011	-0.2261	-2.4293	0.013**	-0.2909	-2.4680	0.011**
2012	-0.2129	-2.3757	0.017**	-0.2529	-2.4013	0.017**
2013	-0.1732	-2.0512	0.039**	-0.1082	-2.1356	0.032**
2014	0.1621	2.5118	0.013**	0.1772	2.4817	0.013**
2015	0.2740	2.1382	0.038**	0.3154	2.3340	0.027**
2016	0.3991	2.5321	0.012**	0.4411	2.9768	0.009***
2017	0.4462	2.5931	0.009***	0.4751	3.1417	0.007***
2018	0.4651	3.1190	0.004***	0.5103	3.3221	0.007***
2019	-0.2160	-2.4331	0.011**	-0.2235	-2.9921	0.009***
2020	-0.2270	-2.1721	0.036**	-0.2184	-2.4021	0.017**

Table 2. Spatial regression model results.

Parameters	Traditional regression model		Spatial lag model		Spatial error model	
	Coefficient	Probability	Coefficient	Probability	Coefficient	Probability
Usage_depth	0.4616 (11.30)	0.000	0.4318 (4.96)	0.000	0.3859 (7.62)	0.000
GDPGROW	0.1082 (7.39)	0.000	0.1132 (5.34)	0.000	0.1220 (8.80)	0.000
GTFP	0.2719 (9.23)	0.000	0.2842 (5.78)	0.000	0.3182 (2.64)	0.008
GREDIT	0.0159 (-2.51)	0.014	0.2841 (-5.77)	0.000	0.3713 (-8.58)	0.000
Digit_level	0.0786 (7.22)	0.000	0.0642 (2.48)	0.016	0.2083 (2.59)	0.010
F	19.5925					
Spatial error factor			0.1987 (3.94)	0.000	0.1392 (3.99)	0.000
R2	0.951439		0.955282		0.971725	
Log-likelihood function value	18.8587		19.2816		19.4932	
AIC	-25.7175		-24.5633		-26.9864	
BIC	-23.3301		-21.778		-24.5991	

As can be seen from Table 2, the OLS model with F=19.5925, and the five indicator degrees of depth of digital financial use, economic growth rate, green total factor productivity, foreign direct investment, and digital financial digitization all pass the significance test. However, by comparing the three models of OLS, SEM, and SDM, after taking into account the spatially interrelated characteristics of each indicator element, the fit of the model improves from 0.951439 to 0.955282 and 0.971725; the log-likelihood estimates improve from 18.8587 to 19.2816 and 19.493225; the AIC value decreases from - 25.7175 decreases to -24.5633, -26.9864; from OLS to SDM model, the BIC value decreases from -23.3301 to -24.5991. Therefore, combining the above evaluation criteria, SEM and SDM models are better than OLS models, and it is concluded that when there is a spatial clustering characteristic of the coupled coordination value of Yangtze River Economic Zone, the use of OLS model will cause the estimated value of bias. Further, by comparing the AIC and BIC values, it can be seen that the AIC and BIC values in the SEM model are lower than those in the SDM model, and at the same time, the fit of the SEM model is greater than that of the SDM model, so the SEM model is better than the SDM model. From the SEM model results, the spatial error coefficient value (rho) is 0.1392, which passes the significance test (p=0) indicating that at the provincial level, the coordination values of the two systems are positively influenced by the influence factors of the coordination values of the neighboring cities. The R2 value of the model is 0.9233, which indicates that the five indicators of depth of digital financial use, economic growth rate, green total factor productivity, foreign direct investment, and digital financial digitization explain the model to a good extent under the large sample condition, and all five explanatory variables pass the t-test.

For the spatial regression coefficients of the three models, the coefficient value of depth of digital financial use is 0.3859 and passes the significance test at the 1% level, indicating that the depth of digital financial use has a more significant positive contribution to improving the coordination value of the two systems. The coefficient value of GDP growth rate is 0.1220 and also passes the significance test at the 1% level. The test shows that economic development has a positive contribution to promote the coordinated value of the two systems. At a time when the international environment is facing various complex, severe and uncertain "variables", GDP growth rate has become a "constant" in the resilient and dynamic Chinese economy that continues to add confidence and momentum to the world economy. High-quality economic growth is an accurate economic data, business environment, product quality assurance optimization, accurate resource matching optimal allocation of growth model, is an innovation-driven economic growth model, is energy-saving and high value-added innovation and efficient growth model. High-quality economic development is conducive to resolving systemic financial risks, creating a favorable financial development environment, deepening financial supply-side structural reform, and making finance better serve the development of the real economy. The coefficient value of green total factor productivity is 0.3182, indicating that the improvement of green total factor productivity can promote the development of green innovation more significantly, which in turn promotes the improvement of the coupling and coordination coefficient of digital finance and green innovation, verifying hypothesis 3. The National Development and Reform Commission and the Ministry of Science and Technology recently jointly issued the "Implementation Plan on Further Improving the Market-oriented Green Technology Innovation System (2023-2025)", which strengthens the market-oriented green technology innovation system. -The coefficients of foreign direct investment (FDI) and green innovation (FDI) are calculated as follows The coefficient value of foreign direct investment is 0.3713 and passes the test at the 5% level, indicating that the introduction of foreign direct investment can improve the coordination level of the two systems. It indicates that the increase of FDI can significantly promote the development of green innovation digital finance, which in turn promotes the improvement of the coordination coefficient of coupling digital finance and green innovation. The coefficient value of digital finance digitization is 0.2083 and passes the test at the 10% level, which indicates that the digitization of digital finance can positively improve the coordination level of the two systems.

5. Conclusions and Recommendations

Based on a sample of 11 cities in the Yangtze River Economic Belt from 2011 to 2020, this paper firstly evaluates the green innovation benefits of each province using the entropy-weighted TOPSIS method and the projection tracing method; subsequently, the spatial exploratory analysis method - Moran index is used to complete the spatial clustering of the coupling scores of digital finance and green innovation benefits and spatial autocorrelation analysis, and after determining the existence of overall spatial correlation of the coupling coordination values, spatial econometric models-spatial lag model and spatial error model-are established for spatial regression analysis to test the effects of five indicators, namely, depth of digital finance use, economic growth rate, green total factor productivity, foreign direct investment, and digital finance digitization, on the the impact of regional coupled and coordinated development.

The results show that, first, from the direct impact, the increase of green innovation level can pull the increase of regional coupling and coordination benefits, and the coefficient of this pull effect reaches the maximum in 2020, which may be related to the characteristics of digital technology's rapid self-innovation and replication in a short period of time, and there is regional heterogeneity in this impact. Second, from a global spatial perspective, the global Moran index transforms from negative in 2011 to 0.4651 in 2018, and later transforms from positive to negative again by 2020 due to the impact of the epidemic. The patterns of the global effects of green innovation and digital finance are similar, and the coupled coordination values of the regions differ globally, with a significantly higher degree of coordination in the eastern region than in the western region, with coordinated green innovation activities among the regions of the provinces and reduced overall differences within the region. Third, from the local spatial perspective, green innovation by 2020 shows mostly random distribution locally, with Shanghai region in the eastern part of the Yangtze River Economic Belt showing high and high aggregation and Sichuan province region in the western part of the Yangtze River Economic Belt showing high and low aggregation, with Shanghai always ranking first in green innovation benefits, Zhejiang region having higher coupling coordination benefits than Jiangsu region overall and Sichuan province having poorer coupling benefit values, indicating that coupling aggregation benefits is comprehensively influenced by the total economic volume, economic model, and science and technology level, i.e., under a certain economic volume, the more developed the economic model and science and technology level, the higher the green innovation benefit of the region.

Based on the findings of this paper, the following suggestions are made for the coordinated development of digital economy and green innovation within the Yangtze River Delta city cluster:

First, encourage scientific and technological research and innovate digital technology. From the empirical results of this paper, the level of digital finance and local green innovation benefits are both higher in regions with better coupling coordination between digital finance and regional green innovation, and digital finance and regional green innovation show a trend of resonance in the same frequency. The reason for this is that, on the one hand, some of the development conditions of digital finance and green innovation overlap, such as regional innovative enterprises, universities and research institutions have both the digital On the other hand, direct green innovation activities aiming at large-scale innovation are not in line with the actual needs, and digital finance, as an emerging knowledge-complex economic model with its own natural green attributes and innovation, can objectively improve the economic basis of green innovation and promote the development of green innovation. Therefore, it will be an important direction for future development to continuously encourage scientific and technological research and improve the level of digital economy and green innovation benefits through digital technology innovation.

Second, weakening the obstruction of factor flow by regional borders and accelerating regional economic cooperation. According to the research results of this paper, the coupled and coordinated development value of digital finance and green innovation in space is more developed in the eastern region than in the western region, and there are also obvious differences among cities in different provincial administrative regions, ranking Shanghai, Zhejiang and Anhui in order, and the overall level of disparity among provinces is large, which is due to the different characteristics of economic development among provinces on the one hand, such as the developed heavy industry in Jiangsu On the other hand, the spatial clustering effects in this paper are mostly found within the provincial boundaries, and there are few cross-provincial clustering effects (except for Shanghai and its surroundings), because the provincial boundaries have hindered the free flow of factors to a certain extent. In response to this situation, the coordinated development of digital finance and green innovation in the region should be promoted by weakening the hindrance of administrative boundaries to factor flow, strengthening inter-provincial economic cooperation and factor flow, and ensuring the effective implementation of regional collaboration rules in the construction of large markets.

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