Coupling and Influencing Factors of Digitalization of Agricultural Product Distribution, Agricultural Technology Innovation and Rural Revitalization

——Based on the Empirical Test of 30 Provincial Panel Data in China

*Zian Jin

School of business administration, Liaoning Technical University, Huludao, Liaoning, 125105, China

Email: *2417504347@qq.com

Abstract. Using the coupling coordination degree model, this article measures the coupling coordination level of the comprehensive evaluation index system of digitalization of agricultural product circulation, agricultural technology innovation, and rural revitalization in 30 provinces (autonomous regions and municipalities directly under the central government) in China from 2011 to 2021. The temporal and spatial characteristics of the coupling coordination degree are analyzed through the spatial autocorrelation model. The coupling coordination degree has been found to be steadily increasing based on the comprehensive evaluation index system of the three systems. The coordination level has improved from mildly dysfunctional to barely coordinated, suggesting that there is still room for improvement. The results show a positive spatial correlation between the provinces in terms of coupling coordination level. The local spatial clustering characteristics of the coupling coordination degree are dominated by the 'high-high' clustering area in the east and the 'low-low' clustering area in the west.

Keywords: Digitalization of circulation; technological innovation; rural revitalization; spatiotemporal characteristics; coupling coordination degree;

1 INTRODUCTION

After the rural revitalization strategy was put forward, the development of China's agricultural modernization has steadily improved, but there are still some problems, such as the Inadequate logistics system, lengthy circulation of agricultural products, high costs, insufficient digital development and limited agricultural innovation capacity, which hinder the development of rural revitalization, and there is still a gap between the basic realization of agricultural and rural modernization in 2035. In order to promote the process of rural revitalization, it has become crucial to improve the construction of logistics systems in rural areas and promote the development of rural technological

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innovation. In terms of agricultural product circulation system, Yang Haili [1] believes that modernized agricultural product circulation system plays a decisive role in rural revitalization. Zhao Lian Ge [2] believes that the high-quality development of the agricultural product circulation industry is a powerful tool for activating and promoting the rural economy. In terms of technological innovation, the essence of science and technology innovation-driven rural revitalization research is to use advanced production technology in the production system to improve the level of modernization of agriculture and rural areas. The focus of this process is to seize the core advantages of "people, materials and industry" [3-4].

Contribution of this study: Although the literature has explored the causal relationship between the circulation system, technological innovation and rural revitalization, few scholars have taken the level of digitalization of agricultural circulation, the level of agricultural innovation and rural revitalization as a whole to study their level of coordination, to explore how to achieve the sustainable development of agriculture and the prosperity of the countryside economy through the organic combination of the three, and to provide a new path for the enhancement of the degree of coupling and coordination of the provinces, and at the same time to provide new implementation strategies for the provinces. This paper contributes to the research in this field by providing new paths for each province to enhance the degree of coupling and coordination, as well as new implementation strategies for each province.

2 STUDY DESIGN

2.1 Establishment of the Indicator System

Combined with the previous related research, the article comprehensively considered the causal relationship between rural revitalization, digitalization of agricultural product circulation and agricultural technology innovation, and established a three-system evaluation index system as shown in the following table. (Table 1)

Table 1. Comprehensive Evaluation Indicator System for Digitalization of Agricultural Product Circulation, Agricultural Technology Innovation and Rural Revitalization

target level	standardized layer	indicator layer	causality	target level	standardized layer	indicator layer	causality
Rural revitalization	industry thriving	Per capita primary sector output (billion yuan)	+	Digitization of agricultural distribution	Level of development of rural informatization	Rural broadband subscription rate (%)	+
		Grain production (kg/ha)	+			Number of agrometeorological monitoring stations (number)	+
		Total power of agricultural machinery (10,000 kilowatts)	+			Share of rural cable radio and television subscribers (%)	+
		Effective irrigated area (thousands of hectares)	+		Level of rural circulation development	Share of administrative villages with postal access (%)	+
	ecologically livable	Forest cover (%)	+			Rural delivery routes (kilometers)	+
		Non-hazardous treatment rate of domestic waste (%)	+			Year-on-year growth in fixed-asset investment in information	+

		Number of public toilets (seats)	+
		Number of rural doctors and health workers (per 10,000 population)	+
		Integrated water supply capacity (10,000 m3/day)	+
	Local customs and civilization	Local fiscal expenditure on education (billion yuan)	+
		Illiteracy/population aged 15 and over (%)	-
		Integrated population coverage of television programs (%)	+
	Effective governance	Ratio of disposable income of urban and rural residents (%)	+
		Ratio of consumption expenditure of urban and rural residents (%)	+
		Rural population (10,000 persons)	+
	prosperous	Per capita disposable income of rural residents (yuan)	+
		Consumption expenditure on food for rural residents (yuan)	-
		Rural self-employment (10,000 persons)	+
		transmission technology services (without farmers) (%)	
	Level of development of rural digital industries	Population served by unit business outlets ((10,000 persons	-
		Number of Taobao villages (number)	+
		Percentage of firms with e-commerce trading activities (%)	+
Agricultural technology innovation	Agricultural innovation inputs	Investment in fixed assets in scientific research and technological services (excluding farm households) up from the previous year (%)	+
		Funding for agricultural science and technology (in millions of yuan)	+
		Agricultural scientists and technicians (persons)	+
	Agricultural innovation outputs	Number of patents disclosed in agriculture (number)	+

Rural revitalization. Referring to T.C. Hsieh[5] , Tan YanZhi et al.[6] 's research ideas and methods, relevant proxy variables are selected, and entropy weight method is applied to construct the rural revitalization index system (Table1).

In 2018, China formally announced the Strategic Plan for Rural Revitalization (2018-2022), which, for the first time, constructed the rural revitalization The main indicators of the strategic plan. This paper refers to existing systems and research results to construct an indicator system for rural revitalization, which helps to evaluate the implementation results of rural revitalization in an all-round and scientific way and provides a solid basis for the decision-making process.

Digitalization of Agricultural Distribution. Most of the researches on the circulation of agricultural products are qualitative analyses and lack of empirical measurements, and the construction of a modern circulation system for agricultural products is an inevitable choice. Based on the "three-dimensional" perspective of modern circulation theory, this paper refers to the relevant studies of Liu Jiangang, Han Nan and Zhang Meijuan, etc. [7], and constructs a three-dimensional system including the development level of rural informatization, the development level of agricultural product circulation and the level of rural digital industrialization. Based on the "three-dimensional" perspective of modern circulation theory, this paper constructs an index evaluation system for the digitalization level of agricultural product circulation, which includes three dimensions: the development level of rural informatization, the development level of agricultural product circulation and the level of rural digital industrialization.

Technological Innovation in Agriculture. On the measurement of innovation level [8], single indicators such as the number of patent applications or authorizations, the number of registered trademarks and so on are mostly used as alternative indicators, or are measured by constructing a comprehensive indicator of innovation level. On the basis of existing research, this paper constructs the indicator system of agricultural innovation level in each province from two aspects: agricultural innovation input and agricultural innovation output.

2.2 Research Methodology

Coupled Coordination Degree Models.

$$C = 3 \times \left[\frac{U_a U_b U_c}{(U_a+U_b+U_c)^3}\right]^{1/3} \tag{1}$$

$$T = \alpha U_a + \beta U_b + \delta U_c \tag{2}$$

$$D = (C \times T)^{1/2} \tag{3}$$

Among them.U_a , theU_b andU_c are the rural revitalization index, the agricultural product circulation digitalization index and the agricultural technology innovation index, respectively; α, β and δ are the weight coefficients of each system, which are taken as$\alpha = \beta = \delta = 1/3$; C, T and D are the coupling degree, comprehensive score and coupling coordination degree, respectively. Meanwhile, D is categorized as follows: [0, 0.1) for extreme dysfunction, [0.1, 0.2) for severe dysfunction, [0.2, 0.3) for moderate dysfunction, [0.3, 0.4) for mild dysfunction, [0.4, 0.5) for verging on dysfunction, [0.5, 0.6) for barely coordinated, [0.6, 0.7) for primary coordinated, [0.7, 0.8) for intermediate coordinated, and [0.8, 0.9) for good coordination, and [0.9, 1] for quality coordination.

Spatial Autocorrelation Models. The overall spatial relevance of rural revitalization, digitization of agricultural product distribution and technological innovation was assessed by testing through a global spatial autocorrelation model, expressed using the global Moran index I.

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i-\bar{x})(x_j-\bar{x})}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \tag{4}$$

The spatial autocorrelation model was tested by using the neighbor weight matrixW_{ij} , the number of samples n, the number of observations x, and the sample varianceS^2 , the global Moran index I was calculated. The global Moran index ranges between [-1,1], where I>0 indicates the presence of spatial positive correlation, I<0 indicates the presence of spatial negative correlation, and I=0 indicates that the spatial distribution of the observations is random. For the local spatial autocorrelation test, a Moran scatterplot was used to decompose the global Moran index I into individual spatial units, with the I_i denoting the local Moran index. The formula is as follows:

$$I_i = Z_i \sum_{i=1}^{n} W_{ij} Z_{ij} \tag{5}$$

$$Z_i = \mathrm{x_i} - \bar{\mathrm{x}}, \;\; Z_j = \mathrm{x_j} - \bar{\mathrm{x}} \tag{6}$$

2.3 Data Sources

This paper presents an in-depth and comprehensive empirical analysis based on linked data from 2011 to 2021 for 30 provinces in China (excluding Tibet, Hong Kong, Macao, and Taiwan), which are categorized into four major regions, namely Eastern, Central, Western, and Northeastern, according to the geographic classification criteria of the National Bureau of Statistics (NBS). This paper brings together data from a variety of sources, including China Industrial Statistical Yearbook, China Rural Statistical Yearbook, China Statistical Yearbook, China Science and Technology Statistical Yearbook, as well as a number of provincial statistical yearbooks, the Cathay Pacific database and the EPS data platform. The data related to innovation patents and the number of Taobao villages come from the China Knowledge Network patent database and the Ali Research Institute. For the missing data of some regional indicators, the interpolation method was used to fill in the data.

3 Analysis of Results

3.1 Composite Index Analysis

By using the entropy power method, the comprehensive indexes of rural revitalization, agricultural product distribution digitalization and agricultural technology innovation were calculated from 2011 to 2021 (Fig. 1). The comprehensive index of rural revitalization, agricultural product circulation digitalization and agricultural technology innovation in China shows an overall growth trend. The index of digitalization of agricultural product circulation increased from 0.095 to 0.235, with an average annual growth rate of 14.76%; the index of agricultural technology innovation increased from 0.084 to 0.171, with an average annual growth rate of 10.22%. The rural revitalization index grew relatively slowly, from 0.445 to 0.507, with an average annual increase of 1.41%. The average value of the rural revitalization index is the highest in this period (0.478), while the average values of the index of digitalization of agricultural product circulation and the index of agricultural technology innovation are lower, at 0.153 and 0.119 respectively, which is mainly due to the fact that China is relatively late in the digitization of agricultural product circulation and agricultural technology innovation, and the potential of the future scale of development needs to be further stimulated.

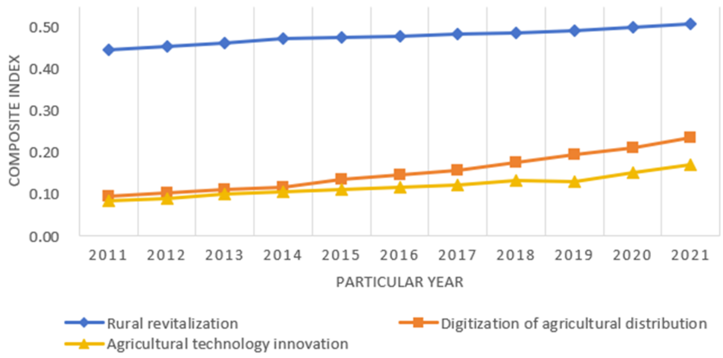

Fig. 1. Trends in the Composite Index of Digitization of Agricultural Product Circulation, Agricultural Technological Innovation and Rural Revitalization

3.2 Spatial and Temporal Characteristics of Coupling Coordination Degree

Characteristics of Spatial and Temporal Changes. After measuring the coupling coordination degree of digitization of agricultural product distribution, agricultural technology innovation and rural revitalization in China from 2011 to 2021 (Fig. 2), it is observed that the coupling coordination degree of the whole country has shown a steady upward trend from 0.372 to 0.487, with an average annual increase of 3.08%. The type of coupling coordination degree shifted from mildly dysfunctional to on the verge of dysfunctional.

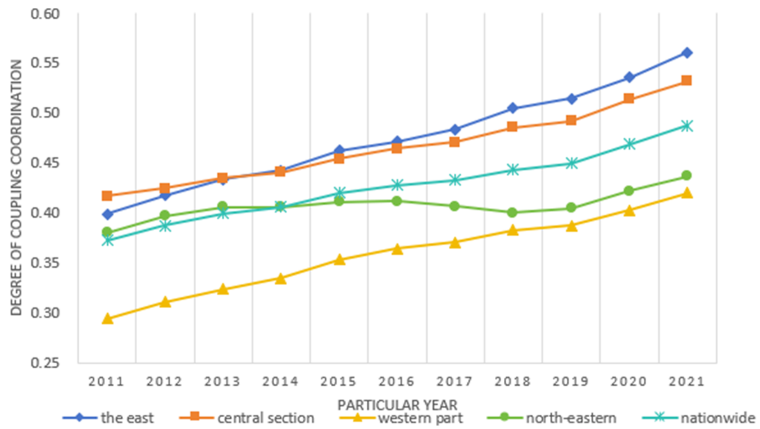

Fig. 2. Trends in the coupling and coordination degree of digitization of agricultural prodct distribution, agricultural technology innovation and rural revitalization

Spatial Distribution Characteristics. （1）Regional level. The tripartite coupling coordination of the eastern, central and western regions continue to grow, while the northeastern region shows fluctuating growth. Within the period from 2011 to 2021, the coupling coordination degree of the eastern region increased from 0.399 to 0.561, with an average annual growth of 4.05%; the central region increased from 0.417 to 0.532, with an average annual growth of 2.75%; the western region increased from 0.294 to 0.420, with an average annual growth of 4.29%; and the northeastern region increased from 0.380 to 0.437, with an average annual growth of 1.49%. The average values of the coupling degree of coordination in the eastern, central, western and northeastern regions are 0.475, 0.466, 0.358 and 0.407, respectively, with large differences, showing a decreasing characteristic of "eastern-central-northeastern-western". There is a big difference, showing the decreasing characteristic of "East-Central-Northeast-West".

（2）Provincial level. In 2011, the overall level of national coupling coordination was low, with most provinces in a state of mild dissonance; in 2014, Shandong took the lead in entering the primary coordination stage, Zhejiang and Henan entered the basic coordination stage, the central and eastern regions were roughly on the verge of dissonance, and the western regions were roughly in a state of mild dissonance; in 2017, Guangdong, Zhejiang, and Jiangsu took the lead in reaching the primary coordination stage, Fujian reached the basic coordination stage, and Anhui, Hubei, and Sichuan reached the basic coordination stage. stage, and Anhui, Hubei, and Sichuan provinces also reached the basic coordination stage; in 2021, four provinces - Jiangsu, Zhejiang, Shandong, and Guangdong - reached the intermediate coordination stage, and Henan and Hebei reached the primary coordination stage. Meanwhile, the number of provinces reaching the basic coordination level and above increases to 12 (Table 2). Overall, the degree of coordination among provinces in the above areas has generally improved, with provinces such as Jiangsu, Zhejiang, Shandong and Guangdong achieving a relatively high degree of coupled coordination.

Table 2. Degree of coupling and coordination between digitalization of agricultural product distribution, agricultural technology innovation and rural revitalization in each province

provinces	2011	2014	2017	2021	provinces	2011	2014	2017	2021	provinces	2011	2014	2017	2021
Beijing	0.320	0.359	0.373	0.422	Anhui	0.391	0.466	0.516	0.557	Shanxi	0.343	0.388	0.408	0.462
Tianjin	0.259	0.298	0.323	0.357	Jiangxi	0.346	0.376	0.434	0.501	Gansu	0.269	0.312	0.339	0.399
Hebei	0.415	0.467	0.499	0.604	Henan	0.464	0.505	0.524	0.601	Qinghai	0.167	0.196	0.216	0.267
Shanghai	0.290	0.312	0.309	0.332	Hubei	0.433	0.474	0.500	0.570	Ningxia	0.193	0.226	0.253	0.319
Jiangsu	0.539	0.600	0.644	0.716	Hunan	0.547	0.466	0.494	0.552	Xinjiang	0.292	0.323	0.342	0.389
Zhejiang	0.478	0.525	0.615	0.730	Inner Mongolia	0.320	0.363	0.363	0.399	Liaoning	0.404	0.433	0.427	0.459
Fujian	0.415	0.460	0.515	0.595	Guangxi	0.351	0.402	0.451	0.476	Jilin	0.338	0.362	0.356	0.394
Shandong	0.548	0.589	0.647	0.731	Chongqing	0.307	0.349	0.404	0.453	Heilongjiang	0.398	0.425	0.436	0.457
Guangdong	0.503	0.538	0.617	0.762	Sichuan	0.412	0.458	0.504	0.551	Average value	0.360	0.397	0.430	0.489
Hainan	0.223	0.277	0.296	0.360	Guizhou	0.270	0.316	0.390	0.436					
Shanxi	0.319	0.357	0.356	0.409	Yunnan	0.308	0.350	0.407	0.468					

Spatial Correlation Characteristics. This paper conducts global and local autocorrelation analyses of tripartite coupling coordination using GeoDa software. The weight matrix for global autocorrelation analysis is the inverse of the absolute value of inter-provincial distances.

(1) Global spatial autocorrelation. By calculating the global Moran index I value of the three-way coupling coordination degree from 2011 to 2021 (Table 3). All I values are positive and all pass the significance test (z>1.96, P<0.05), which indicates that there is a significant positive spatial correlation of the three-party coupling coordination degree, i.e., the coupling coordination degree is spatially positively correlated .Within 2011 to 2021, the I value of the global Moran index shows a fluctuating upward trend from 0.150 to 0.173, which indicates that The coupling coordination degree of digitalization of agricultural product distribution, agricultural technology innovation and rural revitalization in China shows a positive spatial correlation as a whole, and this correlation is gradually increasing.

Table 3. Global spatial autocorrelation of the coupled coordination degree of agricultural product distribution digitalization, agricultural technology innovation and rural revitalization

particular year	2011	2012	2013	2014	201	2016	2017	2018	2019	2020	2021
I	0.150	0.155	0.161	0.175	0.172	0.172	0.182	0.190	0.191	0.183	0.173
Z	2.493	2.587	2.678	2.875	2.828	2.812	2.973	3.084	2.867	2.984	2.890
P	0.016	0.014	0.013	0.009	0.011	0.012	0.009	0.007	0.008	0.009	0.010

(2) Local spatial autocorrelation. The local spatial autocorrelation analysis reveals the clustering state of the coupling coordination degree of each province, and draws the Moran scatter plots for 2011, 2014, 2017 and 2021 to visualize the spatial distribution of the coupling coordination degree and the evolution trend among the provinces (Figure 3).

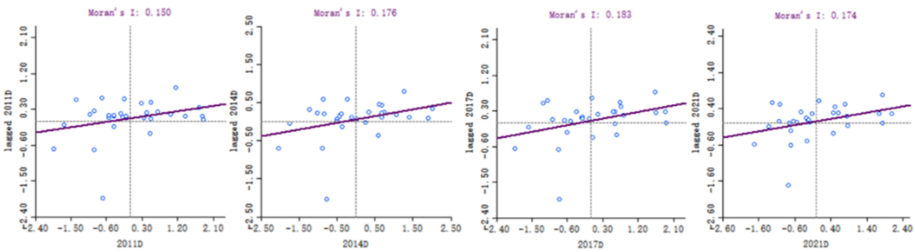

Fig. 3. Scatterplot of the coupling coordination degree of digitalization of agricultural product distribution, agricultural technology innovation and rural revitalization

According to Figure 3, it can be observed that the index distribution of coupling coordination degree in local spatial autocorrelation is mainly concentrated in the first and third quadrants, which indicates that "high-high" and "low-low" agglomeration phenomena are dominant, indicating that there is an obvious spatial spillover effect of this index. In 2011, "high-high" agglomeration areas were mainly distributed in the east, covering five provinces, including Jiangsu, Zhejiang and Fujian; "low-high" agglomeration areas were mainly Shanghai and Jiangxi; and "low-low" agglomeration areas were mainly Shanghai and Jiangxi; and "low-high" agglomeration areas were mainly Shanghai and Jiangxi; and "low-low" agglomeration areas were mainly Shanghai and Jiangxi. In 2014, the overall trend was relatively stable, except for Hunan, which showed a trend of shifting to the "high-high" agglomeration area; in 2017, Jiangxi and Hunan jumped to the "high-high" agglomeration area; in 2020, the "low-high" agglomeration area will be the "low-high" agglomeration area; in 2020, the "low-high" agglomeration area will be the "high-high" agglomeration area. In 2017, Jiangxi and Hunan jumped to the "high-high" agglomeration area; in 2021, the change is relatively stable. In summary, the eastern region is characterized by "high-high" agglomerations, while the western region is characterized by "low-low" agglomerations, and the overall performance is relatively stable.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

(1) The composite indices of digitalization of agricultural product distribution, agricultural technology innovation and rural revitalization in China have all shown growth. The growth rate of the index of agricultural product circulation digitalization is obvious, while the index of agricultural technology innovation and rural revitalization grows more slowly.

(2) The coupling coordination of agricultural product circulation digitalization, agricultural technology innovation and rural revitalization has shown a steady growth, gradually developing from a mild disorder to a barely coordinated one, and the overall coordination level needs to be further improved.

(3) There is a significant positive spatial correlation in the coupling coordination degree. Regions with a higher degree of coupling coordination tend to agglomerate, while regions with a lower degree of coupling coordination also show a tendency to agglomerate. In terms of localized spatial agglomeration characteristics, the eastern region is dominated by "high - high", while the western region is dominated by "low - low".

4.2 Recommendations

(1) Accelerating the development of digitalization and technological innovation in the circulation of agricultural products

In terms of digital agricultural product circulation, firstly, digital infrastructure in rural areas should be strengthened to gradually realize the balanced development of the digitalization of agricultural product circulation among different regions; secondly, Internet of Things (IoT) technology should be introduced to optimize the logistics of agricultural products, increase the efficiency of cold-chain logistics, reduce wastage, improve warehouse management, and reduce the loss of inventory; thirdly, a comprehensive digital agricultural platform should be established to integrate production, circulation and sales, and to Provide real-time market information and trade opportunities.

In terms of technological innovation, first, it is necessary to provide training in digital technology for farmers so that they can make rational use of digital tools to address the shortcomings in rural scientific knowledge and rural civilization; second, it is necessary to make use of big data to analyze agricultural information and provide scientific decision-making support; and third, it is necessary to strengthen the Government's ability to provide financial support and tax incentives to encourage innovative research and development in the field of agricultural technology by enterprises and research institutes. Fourth, the innovation environment should be optimized, and the protection of relevant innovation industries should be continuously strengthened to enhance the motivation of agricultural innovation talents. Fifth, it is necessary to continue to provide scientific and technological innovation platforms to provide support for rural revitalization.

(2) Enhancing the coordinated interaction between the digitalization of agricultural product distribution, agricultural technology innovation and rural revitalization

First, the Government should formulate comprehensive policies to encourage the digital development of distribution and agricultural technological innovation, and policy coherence and integration are crucial to promoting the development of these three areas. Second, it should encourage the sale of agricultural products through digital marketing and e-commerce platforms to improve product coverage and increase sales channels, so as to inject new economic impetus into rural revitalization. Third, an industry synergy mechanism should be established to promote the synergistic development of agriculture, digital technology and rural revitalization industries to form complementary advantages and promote digitization and innovation throughout the industry chain. At the same time, a monitoring and evaluation mechanism will be established to understand in real time the progress of digital agricultural product circulation and agricultural technology innovation, and to adjust policies and measures in a timely manner to ensure that all efforts are coordinated and advanced.

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