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Management Mode Innovation and Path Selection of Digital Economy for Rural Industry Revitalization Based on Genetic Algorithm

Cheng Shao[1,*]
[1] College of Economics and Management, Jiangxi University of Technology, Nanchang, Jiangxi, 330098, China
Corresponding authors: (e-mail: shaoc2023@126.com).

Abstract: As a large agricultural country in China, the development of rural industry is a key part of realizing rural revitalization. The article takes 31 provinces (autonomous regions and municipalities directly under the central government) in China as the object of empirical research, and constructs the evaluation system of the level of development of digital countryside industry from four dimensions: digital countryside capital investment, information base, service base, and industrial development. Then, the model of this paper is used to empirically analyze the influencing factors of digital village industry development. Then, the kernel density estimation and other methods are used to assess the level of industrial development of digital villages, and the spatial and temporal characteristics of digital village development are analyzed in depth from the whole, the region, and the dimensions. Finally, based on the research conclusions and the actual situation, the enhancement path of rural industrial revitalization is proposed. From 2012 to 2024, the comprehensive level of China's rural industrial development as a whole shows the evolutionary characteristics of rising, then declining, then fluctuating level. The development level of rural industrial revitalization has three major characteristics: significant regional differences, uneven development between coastal and inland, and positive correlation with the level of economic development.

Index Terms genetic algorithm, kernel density, rural industry, evaluation system

I. Introduction

To build a modern socialist country in a comprehensive manner, the most arduous and burdensome task is still in the countryside, and comprehensively promoting the revitalization of the countryside is an important support for the realization of Chinese-style modernization [1]. To revitalize the countryside, industry must be revitalized. Industrial revitalization is the primary task and focus of the implementation of the strategy of rural revitalization, an important support for the modernization of agriculture and rural areas, and a key element in promoting the integrated development of urban and rural areas. In order to comprehensively promote the revitalization of the countryside, local governments should actively explore the way to revitalize rural industries, guide and encourage all kinds of social forces to go to the countryside to help revitalize rural industries, and promote the employment and income of farmers [2]-[4].

In recent years, China's rural industrial development has stepped into the fast lane and made considerable achievements. However, while promoting the return of capital, talents and other factors of production to promote the upgrading and integration of rural industries, social forces also face problems such as different motives for going to the countryside, different forms of integration into the industry and different effects produced [5]-[7]. As well as in the mode of industrial revitalization appeared the unreasonable distribution of resources between land and industry, labor and industry, capital and industry, technology and industry, resulting in the obstruction of industrial development [8], [9]. The management process of industrial revitalization does not pay much attention to the changes in market demand, cannot grasp the changes in the modern social market in a timely manner, the positioning of local characteristic products does not link the needs of the consumer market, the product sales route is single, and the backwardness of strategic decisions leads to insufficient resilience of the industrial chain, the supply chain, and the innovation chain [10]-[13].

At the same time, in recent years, the rapid development of cloud computing, the Internet of Things, intelligent manufacturing, automation and other technologies has made the digital economy increasingly important and an important driving force for industrial innovation, and its far-reaching impact has increasingly permeated rural areas. In modern agricultural practice, relying on the “digital + agricultural production” model, from the planting stage, satellite remote sensing, drones, remote video monitoring and other real-time monitoring of production management, to the use of advanced agricultural machinery and equipment, intelligent warehousing systems for harvesting and storage operations, and then to the sales process, the network platform live with goods, farmers -enterprise two-way cooperation and other modes to increase the circulation efficiency of agricultural products [14]-[17]. According to the statistics of China's agricultural network, by the end of 2024, China's installation of Beidou terminal agricultural machinery has reached 2.2 million units, the total number of plant protection drones is nearly 200,000, and the annual operating area has exceeded 2.1 billion mu, and the operational efficiency and precision have reached the international advanced level. While accelerating the transformation of traditional agriculture to modern agriculture, digital technology has also promoted the development of diversified innovation in rural industrial structure and injected fresh vitality into the revitalization of rural industries. For example, big data, AR technology, and holograms are applied to the cultural and ecological resources in the countryside to create rural tourism services with distinctive brands [18]. In addition, by adopting a series of digital technologies such as big data parsing, automated geographic information integration, Internet of Things, and intelligent robots, the accuracy of monitoring and assessing rural natural resources has been significantly improved, thus realizing the scientific allocation and efficient use of resources [19]-[21]. The digital economy, with its unique advantages, not only injects a strong scientific and technological impetus into the rural industrial chain, but also opens up a broader prospect for rural development into to promote the transformation of the industrial structure, enhance the quality of the products, improve the service experience, and show its great potential and value [22], [23]. Although the digital economy empowers industrial revitalization has achieved certain results at present, in general, the digital economy helps the process of comprehensive rural revitalization, still facing the information infrastructure, dynamic allocation of resources, the effectiveness of digital governance of the rural industry, the choice of industrial paths and other realities of the dilemma [24]-[27]. Therefore, there is an urgent need to innovate a suitable digital economy to help rural industrial revitalization management path.

Genetic algorithm is an optimization algorithm that simulates the process of biological evolution in nature and searches for the optimal solution through operations such as selection, crossover and mutation [28]. Genetic algorithms have been used quite a lot in various management problems, Rahman et al [29] used modified genetic algorithm to optimize the management of village government, which involves the optimization of decision-making process, resource allocation, and citizens' participation mode, which provides a scientific basis for the sustainable development of villages, etc. Ebrahimi et al [30] considered the land use scenario, the nature of the territory, the land change, land use demand, and other multi-party factors and applied genetic algorithm in vector structure to achieve rational allocation of land resources.Ehtesham Rasi and Sohanian [31] used genetic algorithm and particle swarm algorithm for multi-objective optimization of sustainability supply chain network with the objectives of minimizing cost and maximizing sustainability performance indicators.Wang [32], in order to boost the supply chain speed of agricultural products, used an improved genetic algorithm to design a two-layer planning optimization model for distribution of agricultural products, which not only improves the distribution efficiency, but also saves costs.Jia et al [33] mentioned that genetic algorithms can optimize the structure of the agricultural industry and also constructed a genetic algorithm-supported evaluation model of the industrial chain system, which further promotes the sustainable development of the agricultural industry. These examples provide a reference for the innovation of management mode of industrial revitalization.

The article first constructs an evaluation system for the industrial development of China's digital countryside based on the principles of scientific rigor, professional representativeness and systematicity. Then for the situation that traditional genetic algorithm is easy to fall into the local optimal solution, it proposes the algorithm model combining chaos algorithm and genetic algorithm with TOPSIS algorithm to measure the level of digital rural industry revitalization The digital algorithm measures the level of rural industry development of 31 provinces in China from 2012 to 2024. Kernel density estimation, trend surface analysis and ESDA exploration are also used to characterize the spatial and temporal evolution of China's rural industry revitalization level. Finally, based on the experimental results, the enhancement path of rural industry revitalization is proposed.

II. Selection and modeling of the indicator system

II. A. Principles of construction of evaluation index system for digital rural industrial revitalization

II. A. 1) Principle of scientific rigor

Scientific rigor requires that we must design evaluation indicators based on relevant domestic regulations in the fields of digital economy and digital agriculture, supported by existing national policies and regulations, to ensure that the indicators are scientific and standardized. In measuring the digital economy, indicators can be designed in terms of digital infrastructure, the growth rate of the digital economy, and the contribution of the digital economy to economic development.

II. A. 2) Principle of professional representation

The principle of professional representativeness requires us to select the indicators with prominent dominant role and greater influence among many influencing factors for analysis [34]. Scientific rigor and professional representativeness are two basic principles for selecting evaluation indicators of digital villages. The adherence to these principles will help to ensure the scientificity, accuracy and reliability of the evaluation indicators, and thus promote the sustainable development of digital villages.

II. A. 3) Systemic principles

In constructing the evaluation indicator system, digital rural development is regarded as a hierarchical whole, and coordination and unity between all aspects are ensured through the establishment of a multi-dimensional indicator system and planning layout. It emphasizes the clear logical relationship between indicators at different levels, embodies the concepts of wholeness and structure, and promotes the sustainability and stability of rural development. Under the systematic framework, the dynamic process of digital village development can be better understood and grasped, cross-sectoral synergy can be achieved, and development strategies can be dynamically adjusted and optimized, so as to promote the construction of digital villages to achieve better results.

II. B. Construction of Rural Industry Revitalization Indicator System

Taking the four aspects of digital infrastructure construction, rural informatization level, rural industrial development and rural quality of life as the underlying logic, the author summarizes and constructs an evaluation system covering four aspects, including digital rural capital investment, digital rural information base, digital service base and digital industrial development, and includes 17 specific indicators as the basis for measuring the level of development of the digital countryside to analyze the development of China's rural industrial revitalization in both temporal and spatial terms. It also includes 17 specific indicators as the basis for measuring the development level of digital countryside, and analyzes the development of China's rural industrial revitalization in both time and space. The evaluation system of digital village industry development is shown in Table 1.

(1) Capital investment in digital village construction

The development of digital countryside must be built on a solid economic foundation, and capital investment is a crucial part. Agricultural production can be regarded as a key secondary indicator when choosing investment funds. Detailed indicators such as the development of agriculture, forestry, animal husbandry and fisheries, the consumption of electricity in the countryside, and the amount of raw grain purchased can comprehensively reflect the capital investment required for the development of digital villages, and also reveal the current state of the infrastructure necessary to support the development of digital agriculture. The analysis and monitoring of these detailed indicators not only help to assess the investment benefits of digital village construction, but also provide important references for future rural development planning, ensuring that the digitization process advances smoothly and achieves sustainable results.

(2) Information infrastructure for digital village construction

The information infrastructure of digital villages is the cornerstone of digital village development, and the communication network plays the role of an important bridge connecting provinces, cities, counties, townships and villages. The development of digital communication reflects the level of investment in information infrastructure in digital villages, including indicators such as cell phone penetration rate, cell phone ownership, and the number of Internet broadband access users, which can profoundly show the level of residents' knowledge and use of the Internet. As for the digitization of life, it directly reflects the degree of residents' payment for digitization through indicators such as the application of digital technology and technology, and the per capita transportation and communication consumption expenditure of rural residents. The improvement of communication network can improve the speed of agricultural market information transmission, effectively connecting the production and sales links, so as to solve the problems of product stagnation caused by poor information transmission. The development of these aspects will provide strong support for the further development of the digital countryside, while also laying a solid foundation for the development of the rural economy.

(3) Digital service foundation of digital countryside

Digital service level is one of the external driving forces to promote the development of digital village industry, and its importance cannot be ignored. This paper chooses three indicators, namely, e-commerce sales, e-commerce purchases and per capita consumption expenditure on household goods and services of rural residents, to reflect the situation of digital transaction level. In this paper, four basic indicators, such as rural delivery lines, total length of postal routes, number of health centers and number of health personnel, are selected to verify the level of services required by residents' life. Rural delivery routes and the total length of postal routes are closely related to the development of the Internet, and the expansion of delivery routes will become an inevitable trend as the level of informatization improves. The number of health centers and the number of health personnel are important reflections of the level of primary healthcare services, and the establishment of the National Integrated Primary Healthcare Management Platform will help promote the extension of healthcare services to the grassroots level, ensure that the infrastructure of the digital countryside's healthcare system is perfected, and realize the goal of basic medical protection for all. This series of initiatives will promote the improvement of the healthcare level of digital villages and lay a solid foundation for the sustainable development of rural areas.

(4) Development of digital industries in digital villages

The development of digital industries provides key digital technologies, infrastructure and solutions for industrial digitization, thus digital industries become a core part of the digital economy, relying on digital elements and technologies in economic activities. The comparison of the number of people employed in the railroad transportation industry and the road transportation industry can be used as an important indicator of the level of industrial digitization, while the speed of development of land transportation indirectly reflects the degree of connection between rural areas and provinces. On the other hand, the digital financial inclusion index comprehensively assesses the degree of digital financial penetration in rural areas in terms of depth of use, breadth of coverage and degree of digital support services. A high index implies a high level of digital financial inclusion, which is positively correlated. The reverse is true. The analysis of these data and indicators helps to provide a comprehensive understanding of the actual situation of the digital development of the industry and provides an important reference for future policymaking and development planning.

Table 1: Digital rural industry development evaluation system

	Target layer	Subsystems	Index
Digital rural evaluation system	Investment in digital rural construction(A1)	Agricultural production(A11)	fishery(A111)
			Total grain production(A112)
			Purchase quantity(A113)
	The information base required in the construction of digital countryside(A2)	Digital communication(A21)	Internet broadband access users(A211)
			Mobile phone penetration(A212)
			Mobile phone ownership(A213)
		Digital life(A22)	Rural residents per capita transport and consumer expenditure(A221)
	Digital service base for digital villages(A3)	Digital transaction(A31)	E-commerce sales(A311)
			E-commerce purchase(A312)
			Rural residents per capita living goods(A313)
			Service consumption(A314)
		Digital service base(A32)	Rural delivery line(A321)
			Health hospital(A322)
			Number of health personnel(A323)
			The length of the postal service(A324)
	Digital industry development in digital villages(A4)	Industry digitization(A41)	Number of employment workers in the railway industry(A4111)
			Number of employment personnel in road transportation(A412)
		Network payment(A42)	Digital puhui financial index(A421)

II. C.Modeling

II. C. 1) Genetic algorithms

The most crucial step for genetic algorithms to achieve hyperparameter tuning is to abstract the problems that need to be solved in practice into problems that can be solved by genetic algorithms. The steps include: coding, calculation of fitness, selection, crossover, and mutation operations [35]. First, a batch of initial solutions is generated as the current solution set of the population. Second, the fitness of each solution in the current solution set is computed. Then operations such as selection, crossover, and mutation are performed to calculate the fitness of each solution of the current population again. Finally, when the iteration termination condition is satisfied, the loop is jumped out and the searched optimal solution is output. The flow of the algorithm is shown in Fig. 1.

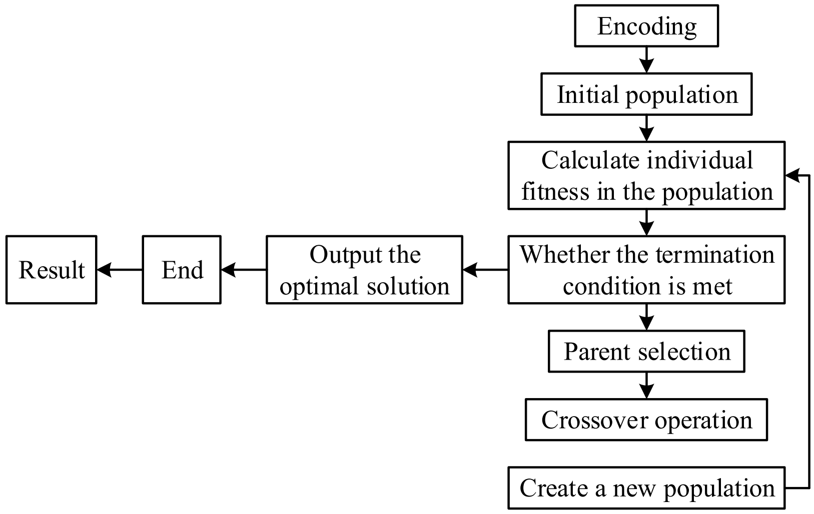


Figure 1: Genetic algorithm process

The improved crossover probability is:

$$p_c = \begin{cases} \dfrac{k_1(f_{\max} - f^{'})}{f_{\max} - f} & \text{if } f^{'} \geq f_{\text{avg}} \\ k_2 & \text{if } \dfrac{f^{'}}{f} \geq f_{\text{avg}} \end{cases} \tag{1}$$

The improved mutation probability is:

$$p_m = \begin{cases} \dfrac{k_3(f_{\max} - f)}{f_{\max} - f_{\text{avg}}} & \text{if } f \geq f_{\text{avg}} \\ k_4 & \text{if } f < f_{\text{avg}} \end{cases} \tag{2}$$

Based on the theoretical derivation of adaptive genetic algorithm is shown below:

(1) Initialize the population

A set of initial populations is randomly generated, and each individual represents the position of a decision scheme in the normalized decision matrix P. Assuming that the population size is N and each individual contains n dimensions, the initial population is denoted as:

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & & \vdots \\ p_{N1} & p_{N2} & \cdots & p_{Nn} \end{bmatrix} \tag{3}$$

where p_i denotes the value of the i th individual in the j th dimension.

(2) Evaluate the adaptation degree

Calculate the fitness value of each individual in the chaotic adaptive genetic algorithm optimization TOPSIS algorithm. Taking the Euclidean distance as an example, the fitness value of individual i is denoted as:

$$F_i = \frac{D_i}{D_i^+ + D_i^-} \tag{4}$$

where D_i^+, D_i^- denote the Euclidean distances from i to the positive and negative ideal solutions, respectively.

(3) Selection

The selection operator is used to select the individuals with higher fitness from the population, which in turn generates the next generation of the population. The roulette wheel selection method is used in the chaotic adaptive genetic algorithm, i.e., individuals are normalized according to their fitness values and a random number r is generated in the interval [0, 1], and individuals with fitness values greater than r are selected as the parent of the next generation population.

(4) Crossover

The crossover operator is used to recombine some features of the parent individuals to produce new individuals. Single point crossover operator is used in chaotic adaptive genetic algorithm, i.e., two parent individuals are cut off at a certain position, and then some of their gene segments are exchanged to get two new offspring individuals.

(5) Mutation

The variation operator is used to introduce randomness, increase the search space and prevent the population from falling into local optimal solutions. Chaotic adaptive genetic algorithm uses normal distribution mutation operator, i.e., some genes in an individual are regenerated with random values according to normal distribution to generate a new offspring individual.

(6) Updating the population

After selection, crossover and mutation operations, a new set of offspring individuals is obtained. Merge the offspring individuals with the parent individuals to get a new population and recalculate its fitness value.

(7) Termination condition judgment

Repeat the above steps until the preset termination condition is reached, i.e. the maximum number of iterations or the minimum fitness threshold is reached.

In the chaotic adaptive genetic algorithm, chaotic factors and adaptive strategies are added to improve the search efficiency and accuracy. Chaotic mapping is used to generate random sequences, which are applied to operations such as selection, crossover and mutation. At the same time, parameters such as selection probability, crossover probability and mutation probability are adaptively adjusted to achieve better performance. The evaluation process of adaptation is described as follows.

For individual i the fitness value F_i, where the Euclidean distance is expressed as:

$$D_i^+ = \sqrt{\sum_{j=1}^{n}(y_{ij} - a_j^+)^2} \tag{5}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}(y_{ij} - a_j^-)^2} \tag{6}$$

Again, the fitness value is:

$$F_i = \frac{D_i}{D_i^+ + D_i^-} \tag{7}$$

II. C. 2) TOPSIS evaluation model

The TOPSIS algorithm, also known as the Approximate Ideal Solution Ranking Method, which ranks the evaluation objects according to their proximity to the idealized target, is a method of comprehensive evaluation based on distance [36]. The specific theory of the algorithm is shown below.

The decision matrix constructed according to the index system is shown below:

$$x = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1,13} \\ x_{21} & x_{22} & \cdots & x_{2,13} \\ \vdots & \vdots & & \vdots \\ x_{16,1} & x_{16,2} & \cdots & x_{16,13} \end{bmatrix} \tag{8}$$

Since the constructed indicators are in different dimensions, the data are dimensionless and the decision matrix is obtained as follows:

$$x = (x_{ij})_{16\times13} \tag{9}$$

Then there is a goal j for countryside i:

$$z_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}} \tag{10}$$

Therefore, the conversion gets:

$$z = (z_{ij})_{16\times 13} \tag{11}$$

where $j = 1,2,...,13$ and i is between 0 and 1.
Calculate the mean value of each indicator:

$$\overline{z}_j = \frac{1}{16}\sum_{i=1}^{1} z_{ij} (j = 1,2,3,...,13) \tag{12}$$

Then the standard deviation of its indicator is:

$$t_j = \sqrt{\frac{1}{16-1}\sum_{i=1}^{16}(z_{ij} - \overline{z}_j)^2} (j = 1,2,...,13) \tag{13}$$

Then the coefficient of variation for each indicator can be obtained:

$$M_j = \frac{t_j}{\overline{z}_j} (j = 1,2,...,13) \tag{14}$$

Finally, the weight values of the different indicators are obtained from the data normalization:

$$w_j = \frac{M_j}{\sum_{j=1}^{13} M_j} (j = 1,2,...,13) \tag{15}$$

II. C. 3) Chaotic Adaptive Genetic Algorithm Accelerated TOPSIS Modeling

TOPSIS algorithm also has some defects in the model evaluation system. In this paper, the following improvements are made to address this situation: firstly, the comprehensive weights are constructed based on the combination of entropy weight method and subjective method. Then, the weighting matrix is constructed based on the normalization matrix and chaotic adaptive genetic algorithm. Further, the absolute ideal solution is determined based on the weighting coefficients determined by the hyperparametric optimization algorithm. Finally, the relative closeness of each scheme to the positive ideal solution is calculated. The experimental flow of optimizing TOPSIS algorithm based on chaotic adaptive genetic algorithm is shown below.

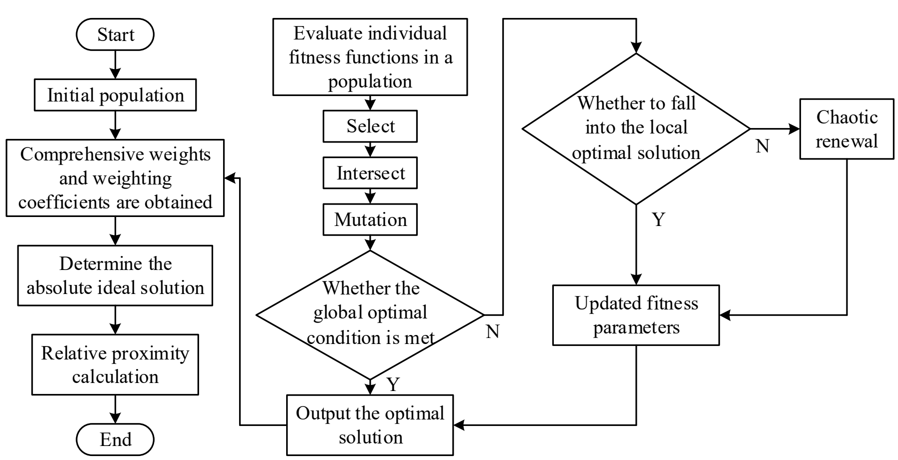


Figure 2: TOPSIS algorithm model optimized by chaotic adaptive genetic algorithm

(1) Weighted synthesis matrix determination. In order to overcome the traditional genetic algorithm is easy to fall into the local optimal solution and ignore the global optimal solution, the constructed comprehensive normalization matrix and the weighting coefficients obtained by using chaotic adaptive genetic algorithm are weighted to obtain the weighted comprehensive matrix. The traversability of the chaotic algorithm is utilized for chaotic optimization, and the Logistic mapping expression is as follows:

$$x_{(n+1)} = \mu x_{(n)}(1 - x_{(n)}) \tag{16}$$

where $n = 1,2,...,0 < x_{(0)} < 1, 0 < \mu \le 4$.

The chaotic adaptive genetic, algorithm optimizes the relative closeness of the objective function as follows:

$$\max \eta(r_i) = \frac{Sd_i^-}{Sd_i^+ + Sd_i^-} \tag{17}$$

The flowchart of the chaotic adaptive genetic optimization algorithm is shown in Fig. 2.

The obtained weighting coefficients r_{ij} are weighted with the composite weights w to obtain the composite matrix as follows:

$$z_{ij} = \overline{w}_j \cdot r_{ij} \tag{18}$$

(2) Determine the absolute ideal solution. In order to solve the inverse sorting problem in the traditional algorithm, the absolute ideal solution method is used to improve the absolute ideal point method in the traditional algorithm. Namely:

$$z_j^+ = \begin{cases} 1, j \in T_1 \\ 0, j \in T_2 \end{cases} \tag{19}$$

$$z_j^- = \begin{cases} 1, j \in T_1 \\ 0, j \in T_2 \end{cases} \tag{20}$$

Where 0 and 1 represent the minimum and maximum standards of the indicator respectively, and T_1 and T_2 represent the benefit-based and cost-based attributes respectively. The weighted improved Euclidean distance of positive and negative ideal solutions using the improved algorithm is given by:

$$\begin{aligned} Sd_i^+ &= \sqrt{\sum_{j=1}^{n} \overline{w}_j (z_{ij} - z_j^+)^2} \, (i = 1, 2, ..., n) \\ Sd_i^- &= \sqrt{\sum_{j=1}^{n} \overline{w}_j (z_{ij} - z_j^+)^2} \, (i = 1, 2, ..., n) \end{aligned} \tag{21}$$

(3) Calculate the relative closeness of each scheme to the positive ideal solution η_i by using Eq.

II. C. 4) Kernel density estimation

Kernel density estimation has the characteristics of model dependence and robustness, this paper uses Gaussian kernel function to analyze the distribution location, shape and ductility of China's scientific and technological innovation capability, the specific formula is as follows:

$$f(x) = \frac{\sum_{i=1}^{n} K\{(x_i - \overline{x}) / h\}}{nh} \tag{22}$$

where $K(\cdot)$ denotes the kernel function. h is the bandwidth. x_i is the sample observations. $\overline{x}$ is the sample observation mean. n is the number of observations.

II. C. 5) ESDA

ESDA is a synthesis of a series of spatial data-based analysis methods and techniques, centered on spatial correlation measures, which can detect spatial data outliers, discover spatial data agglomeration and autocorrelation, and reveal differences and interaction patterns between regions [37]. Global spatial autocorrelation is mainly used to determine whether a phenomenon has a spatial clustering effect or not, which is generally measured by the Moran index ($Moran'sI$) with the following formula:

$$Moran'sI = \frac{N}{\sum_{i=1}^{N}\sum_{j=1}^{N}\omega_{ij}} \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}\omega_{ij}(y_i - \overline{Y})(y_i - \overline{Y})}{\sum_{i=1}^{N}(y_i - \overline{Y})^2} \tag{23}$$

where N is the number of provinces. y is the capability index: $\overline{Y}$ is the mean value of capability index. ω_0 is the spatial weight matrix, and in this paper, the neighboring spatial weight matrix is selected. When $Moran's\ P > 0$, it indicates the existence of spatial positive correlation. When $Moran's\ I < 0$, it indicates the existence of spatial negative correlation. When $Moran's\ I$ tends to 0, it indicates that the observations tend to be randomly distributed. The closer $Moran's\ I$ is to 1, it means that similar observations tend to be spatially clustered, and the closer it is to -1, it means that similar observations tend to be dispersed distribution.

III. Results and analysis of model application

III. A. Data sources and modeling applications

III. A. 1) Data sources

The raw data for the 18 indicators for the 31 provinces (autonomous regions and municipalities directly under the central government) selected in this section come from sources such as the China Statistical Yearbook and the China Rural Statistical Yearbook.

III. A. 2) Model application

The formulae are normalized by Excel and then Matlab is used to program the formulae to achieve projection seeking based on accelerated genetic algorithms to find the optimal solution.

III. B. Analysis based on the optimal projection direction of the indicator and sample projection values

The optimal projection directions and weights of the secondary indicators are shown in Table 2, and the national development level of rural industrial revitalization (projection value) and ranking are shown in Table 3. A~E1 in the table represent Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, respectively.

Table 2: The optimal projection direction and weight of the secondary index

Target layer	Subsystems	Index	Optimum projection direction	Weighting
(A1)	(A11)	(A111)	0.211	0.039
		(A112)	0.238	0.087
		(A113)	0.092	0.031
(A2)	(A21)	(A211)	0.086	0.047
		(A212)	0.134	0.046
		(A213)	0.232	0.091
	(A22)	(A221)	0.305	0.096
(A3)	(A31)	(A311)	0.094	0.053
		(A312)	0.252	0.039
		(A313)	0.311	0.088
		(A314)	0.066	0.052
	(A32)	(A321)	0.057	0.032
		(A322)	0.243	0.043
		(A323)	0.042	0.003
		(A324)	0.31	0.099
(A4)	(A41)	(A4111)	0.237	0.067
		(A412)	0.2	0.051
	(A42)	(A421)	0.117	0.036

III. B. 1) Analysis of optimal projection directions and weights of indicators

As can be seen from Table 2, the optimal projection directions and weights of the four first-level indicators can be obtained based on the optimal projection directions and weights of the 18 third-level indicators. The optimal projection directions are 0.541, 0.757, 1.375, and 0.554 in order, and the weights are 0.157, 0.28, 0.409, and 0.154 in order. Since the weights obtained through the optimal projection direction reflect the size of the contribution of each indicator to the measurement of the level of rural industrial revitalization based on the current data, the digital service base has the largest contribution rate and the digital industry has the smallest contribution rate among the four first-level indicators, so it can be seen that the digital service base has a crucial role in promoting the revitalization of rural industries.

Table 3: National country rejuvenation development level (projection value) and sort

Province	A1		A2		A3		A4		Synthesize	
	Projected value	ranking	Projected value	ranking	Projected value	ranking	Projected value	ranking	Projected value	ranking
A	0.292	17	1.173	2	0.599	1	0.541	4	3.215	1
B	0.26	21	1.087	3	0.384	6	0.356	17	2.839	5
C	0.375	6	0.41	18	0.19	24	0.268	23	1.688	17
D	0.261	20	0.38	20	0.232	20	0.385	15	1.801	15
E	0.348	9	0.375	21	0.197	23	0.443	9	1.644	20
F	0.325	13	0.532	13	0.312	12	0.286	20	1.809	13
G	0.328	11	0.314	26	0.315	11	0.237	26	1.484	24
H	0.365	7	0.223	30	0.216	21	0.27	22	1.584	23
I	0.264	19	1.206	1	0.419	4	0.231	28	3.142	3
J	0.45	2	0.995	4	0.483	3	0.425	11	3.191	2
K	0.427	4	0.893	5	0.522	2	0.548	3	3.002	4
L	0.335	10	0.493	14	0.256	18	0.229	29	1.632	21
M	0.305	15	0.864	6	0.34	9	0.569	2	2.702	6
N	0.232	23	0.534	12	0.401	5	0.283	21	1.759	16
O	0.588	1	0.762	9	0.323	10	0.376	16	2.627	8
P	0.43	3	0.349	23	0.269	16	0.419	13	1.804	14
Q	0.327	12	0.553	10	0.273	15	0.432	10	2.007	9
R	0.323	14	0.459	15	0.282	13	0.531	5	1.962	10
S	0.359	8	0.773	8	0.36	7	0.607	1	2.657	7
T	0.19	25	0.543	11	0.125	29	0.42	12	1.673	18
U	0.109	31	0.786	7	0.163	27	0.243	24	1.822	12
V	0.299	16	0.401	19	0.185	25	0.464	6	1.663	19
W	0.404	5	0.456	16	0.207	22	0.447	7	1.929	11
X	0.17	28	0.306	27	0.282	13	0.416	14	1.364	26
Y	0.184	26	0.285	28	0.26	17	0.233	27	1.2	28
Z	0.158	29	0.261	29	0.075	31	0.341	18	1.111	31
A1	0.285	18	0.152	31	0.341	8	0.098	30	1.365	25
B1	0.156	30	0.333	24	0.252	19	0.243	24	1.169	29
C1	0.192	24	0.318	25	0.138	28	0.325	19	1.353	27
D1	0.234	22	0.354	22	0.168	26	0.445	8	1.591	22
E1	0.177	27	0.433	17	0.121	30	0.059	31	1.167	30

III. B. 2) There are 3 major characteristics of the development level of China's rural industrial revitalization

From Table 3, we can get the best projection value and ranking of 31 provinces (autonomous regions and municipalities directly under the central government), and we can see that there are 3 major characteristics of China's rural industry revitalization level. First, there are significant regional differences in the development level of rural industrial revitalization, with A, J, I, K, and B in the eastern region ranking firmly in the top 5, while B1, E1, and Z in the southwestern and northwestern regions rank last. Second, there is a non-equilibrium between the coast and inland. Third, the level of development of rural industrial revitalization is positively correlated with the level of economic development of provinces (autonomous regions and municipalities directly under the central government).

III. B. 3) Correlation analysis of the 4 level 1 indicators

In order to further deepen the research on the revitalization of rural industries, Pearson correlation was used to measure the intrinsic connection between the four level 1 indicators, and the correlation coefficients between the four level 1 indicators are shown in Table 4 (*, ** indicate significant correlation at the level of 5% and 1% (two-sided), respectively). As a whole, there is a positive correlation between all level 1 indicators, indicating that the requirements of the rural industrial revitalization strategy are mutually influential and inseparable. The significant correlation between financial investment and digital service infrastructure reflects the cross-influence of financial investment and service infrastructure of digital rural industry, which are indispensable.

Table 4: The correlation coefficients between four primary indicators

Primary indicator	A1	A2	A3	A4
A1	1			
A2	0.196	1		
A3	0.376*	0.692**	1	
A4	0.3111	0.855**	0.361*	1

III. C. Cluster analysis

In this paper, on the basis of the evaluation results of the projection-seeking model, in order to more scientifically and rationally carry out the cluster analysis, by calculating the Euclidean squared distance and the sum of squared deviations, and using SPSS to carry out the cluster analysis of 31 provinces (autonomous regions and municipalities directly under the central government), the results of the clustering and stratification of the 31 provinces (autonomous regions and municipalities directly under the central government) in China are shown in Table 5. There are obvious regional differences in the level of rural industrial revitalization in 31 provinces (autonomous regions and municipalities directly under the central government) in China. In terms of the overall spatial layout, from east to west, the level of rural development is decreasing. a and i as the two municipalities directly under the central government in China have an absolute advantage. The second level of provinces is characterized by significant features, all located in the eastern coastal region, strong economic strength, earlier awareness and higher level of rural development. The third level contains the largest number of provinces, 16, which are similar in structure, mostly located in the central and northeastern regions, with insufficient rural development dynamics but high potential. The last level of provinces is mainly located in the western region of China, which is relatively underdeveloped, with inadequate infrastructure, ineffective development of rich resources and slow rural development.

Table 5: The clustering of 31 provinces

Hierarchy	Province
First level	A, I, J
Second level	K, B, M, S, O
Third level	Q, W, R, P, U, F, D, N, V, T, C, L, E, D1, H, G
Fourth level	A1, X, C1, Y, E1, B1, Z

IV. Analysis of the characteristics of the spatial and temporal evolution of the level of revitalization of rural industries in China

IV. A. Analysis of the characteristics of the overall changes in the comprehensive level of China's rural industrial revitalization development

This section applies the kernel density estimation method, and this chapter estimated the kernel density of the comprehensive level of China's rural industrial development in 2012, 2016, 2020 and 2024 respectively, so as to portray the time-series evolution characteristics of China's rural industrial development level from the perspective of the whole region, and the time-series dynamic evolution characteristics of the comprehensive level of rural industrial revitalization and development are shown in Figure 3. ①From the position of the center of gravity of the annual curve of kernel density, the center of gravity migrated to the right in 2012~2016, to the left in 2016~2020, and basically remained unchanged in 2020~2024, indicating that the comprehensive level of China's rural industrial development in the study period of 2012~2024 showed an overall evolutionary characteristic of rising, then declining, and then fluctuating horizontally. ② In terms of the wave height of the main peak of the kernel density curve, there was an increase from 2012 to 2016, a slight decrease from 2016 to 2020, and a substantial rebound from 2020 to 2024, indicating that the differences in the level of rural industrial development among the villages in China show a trend of narrowing, then expanding and then narrowing again. ③ From the number of peaks in the kernel density curve, the co-existence of primary and secondary peaks in 2016 indicates that the development level of rural industries in Chinese villages in 2016 showed a certain degree of polarization, and the number of peaks in 2012, 2020, and 2024 is only one, which indicates that the development level of rural industries in Chinese villages in these years did not show polarization. ④ From the left and right tails of the kernel density curves, the left tail of the corresponding curves in each year is larger than the right tail, showing a left-skewed distribution, and the left tail shows a lengthening trend in 2012-2024, indicating that the number of villages on the left side is more than that on the right side, i.e., more villages with a value of the rural industrial development level smaller than the average value during the period of the study, and the ratio of villages in the low-value area has increased, and the low-value rural industrial development level is obviously distributed in a clustered manner. Clustering distribution is obvious. From the kernel density analysis, it can be found that, in general, China's rural industrial development in terms of the overall development level, the differences between villages, and the degree of polarization all reflect the dynamic evolution characteristics of fluctuations over time.

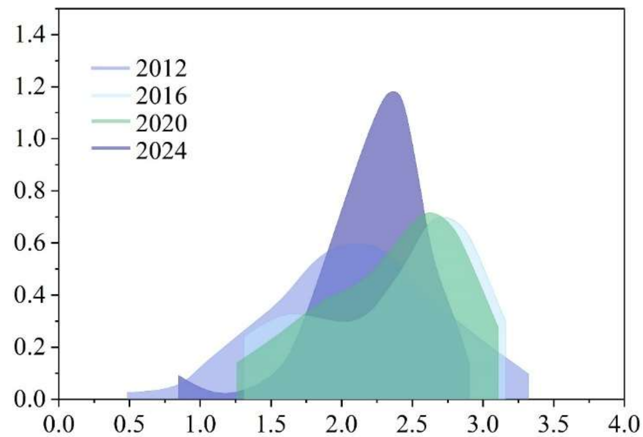


Figure 3: Sequential dynamic evolution characteristics

IV. B. A Multidimensional Review of China's Rural Industry Revitalization and Development

Using the accelerated genetic algorithm projection seeking model, the four level 1 indicators of rural industry revitalization development are measured separately, and the advancement of rural industry revitalization development is shown in Fig. 4, with 2012, 2016, 2020 and 2024 as the representative years. There are certain differences in the level of development of rural industrial revitalization in China, and the overall difference in the development level of rural capital investment, information base and digital industrial development is not significant, but it is significantly higher than the level of development of digital service base. In terms of the trend of change, the development level of rural capital investment shows an upward and then downward trend. The level of information base shows a fluctuating upward trend of different degrees. The development level of digital industry development, on the other hand, basically maintains a small up and down fluctuation trend. It can be seen that the fluctuating increase in the comprehensive level of China's rural industrial development during the 13-year period from 2012 to 2024 is mainly due to the increase in the level of information base. The decrease in the development level of rural capital investment, on the other hand, has become a key factor restricting the sustainable improvement of rural industrial development in the region.

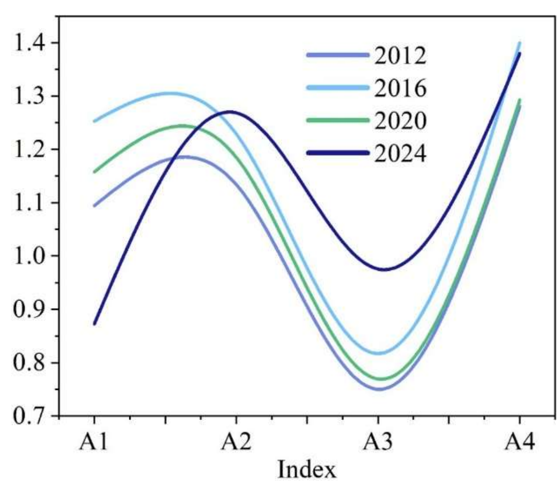


Figure 4: The development of rural industry has been promoted

IV. C. Rural Level Analysis of the Development Level of China's Rural Industry

The comprehensive level of rural industrial revitalization development in each province of China is shown in Figure 5. As shown in the figure, the corresponding rectangular box shapes of villages such as K, O, and A1 are longer, indicating that the values of the rural industrial development level of these villages fluctuate more between 2012 and 2024. In contrast, the villages A, B, E, H and other villages' rural industry development level has not changed much during the 13-year period, maintaining a steady development trend.

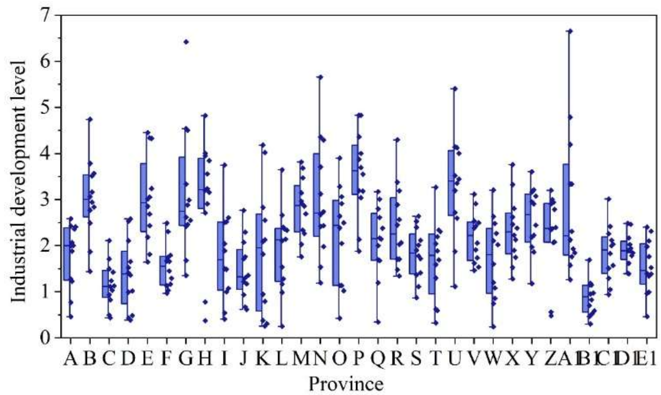


Figure 5: Comprehensive level of development and development of rural industries

IV. D. Evolution of the spatial and temporal pattern of the level of development of China's rural industries

IV. D. 1) Characteristics of the evolution of global spatial patterns

Using the global Moran's I index calculation formula, the global Moran's I index of the development level of rural industries in China in each year from 2012 to 2024 was measured with the help of GeoDa software, and the evolution of the global Moran's I index of the development level of rural industrial revitalization characteristics is shown in Figure 6. The results show that the global Moran's I index of the development level of rural industries in China in each year from 2012 to 2024 is positive, ranging from 0.205 to 0.621, and the P-Value of each year is less than 0.05, i.e., each year passes the significance test. This result indicates that there is a significant positive global spatial autocorrelation in the spatial distribution of China's rural industrial development level during the study period, i.e., the rural industrial development level of local villages not only affects neighboring villages, but is also influenced by neighboring villages. Overall, the global Moran's I index from 2012 to 2024 shows a trend of a small increase, followed by a large decrease and then a small increase, indicating that the global spatial autocorrelation of China's rural industrial development level throughout the study period shows a spiral evolution of “weaker correlation → stronger correlation → weaker correlation → stronger correlation” spiral evolution.

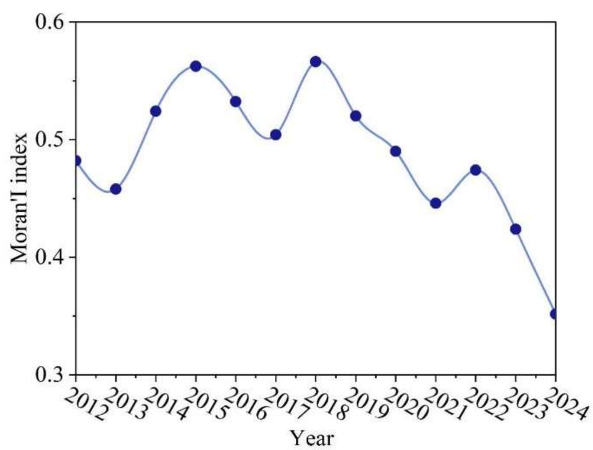
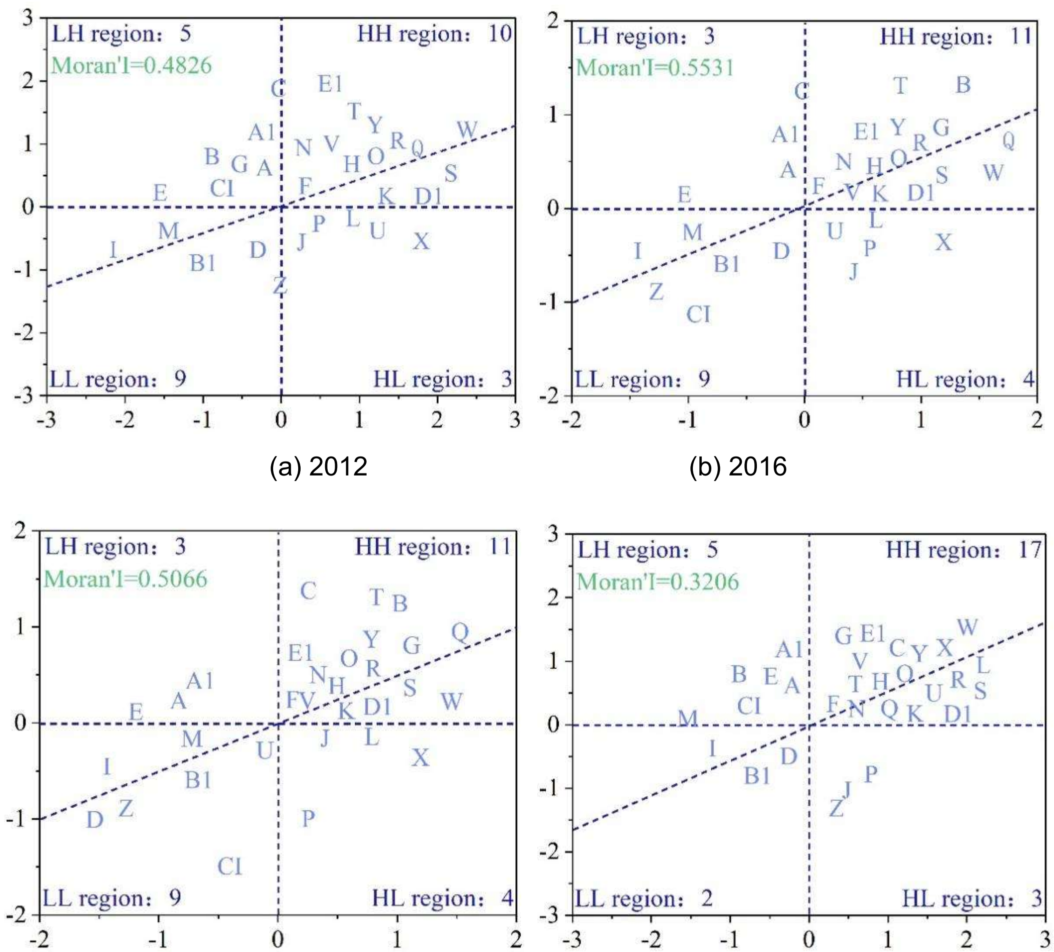


Figure 6: Development level global Moran’s I exponential evolution characteristics

IV. D. 2) Characteristics of the evolution of local spatial patterns

In order to examine the change of local spatial differentiation in the level of rural industrial development, this section plots the local Moran's I scatterplot of the level of rural industrial development in 2012, 2016, 2020 and 2024. The Moran's I scatterplot of the integration development level of rural industrial revitalization is shown in Fig. 7 (Figs. a~d represent 2012-2024, respectively). The bureau spatial pattern pattern is divided into four categories through four quadrants:

The first type is the high - high agglomeration type (HH, located in the first quadrant), which represents a high level of rural industrial development, and the level of rural industrial development in the surrounding neighboring villages is also relatively high, showing a high level of spatial equilibrium correlation and agglomeration of “high in the center and high in the surroundings”. The second type is the low-high agglomeration type (LH, located in the second quadrant), which represents the low level of rural industrial development, but the level of rural industrial development in the surrounding neighboring villages is also relatively high, showing the spatial unbalanced correlation agglomeration state of “low center, high surrounding”. The third type is the low-low agglomeration type (LL, located in the third quadrant), which represents the low level of rural industrial development, and the relatively low level of rural industrial development in the surrounding neighboring villages, and manifests the spatial equilibrium correlation agglomeration state of “low center, low surroundings” at a low level. The fourth type is the high-low agglomeration type (HL, located in the fourth quadrant), which represents a relatively high level of rural industrial development, but the level of rural industrial development in the surrounding neighboring villages is also relatively low, manifesting the spatial unbalanced correlation agglomeration state of “high in the center, low in the surroundings”. HH-type areas are defined as diffusion spillover areas, LH-type areas are defined as polarization effect areas, LL-type areas are defined as low growth areas, and HL-type areas are defined as backward transition areas. As can be seen from the figure, China's rural industrial development at all stages of the local spatial agglomeration phenomenon to a certain extent, the diffusion of mutual spillover areas and low-speed growth areas of the two spatial differentiation characteristics of the evolution of the development of rural industries in the region to occupy the leading. The overall level of rural industrial development has formed a localized spatial agglomeration characterized by high-value clusters (HH) represented by K, R, L and other villages, and low-value clusters (LL) represented by I, B1, D and other villages.



(a) 2012 (b) 2016

(c) 2020 (d) 2024

Figure 7: The rural industry revitalizing the fusion development level Moran’s I

The evolution of the local spatial pattern of the development level of rural industrial revitalization from 2012 to 2024 is shown in Figure 8, and the local spatial pattern of the development level of China's rural industries from 2012 to 2024 shows the quantitative characteristics of “HH>LL>HL>LH” in general. It is not difficult to find out that there is a large degree of spatial neighborhood peer effect in China's rural industrial development level, in general, the number of HH-type villages rises in fluctuation, while the number of LL-type villages shows a more obvious fluctuating downward trend, and the number of HL-type and LH-type villages basically maintains a low number of fluctuation trend, which reflects that villages with a low level of spatial pattern of rural industrial development are moving towards a high level of spatial concentration in 2012-2024. This reflects the fact that villages with low level of industrial development in China's countryside are slowly developing in the direction of high level of agglomeration.

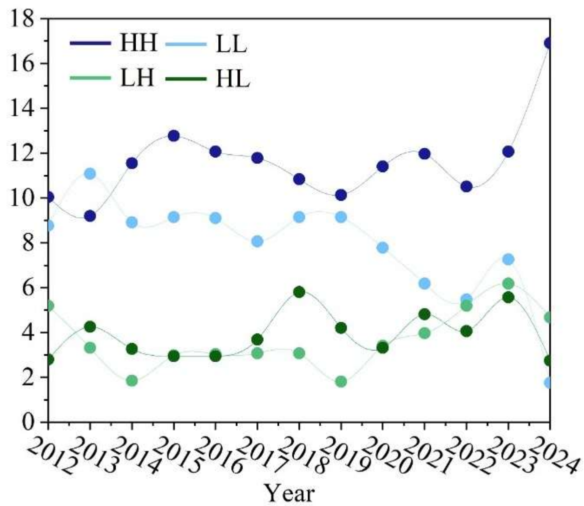


Figure 8: Spatial pattern evolution characteristics

IV. E. Trend surface analysis of China's rural industry development level

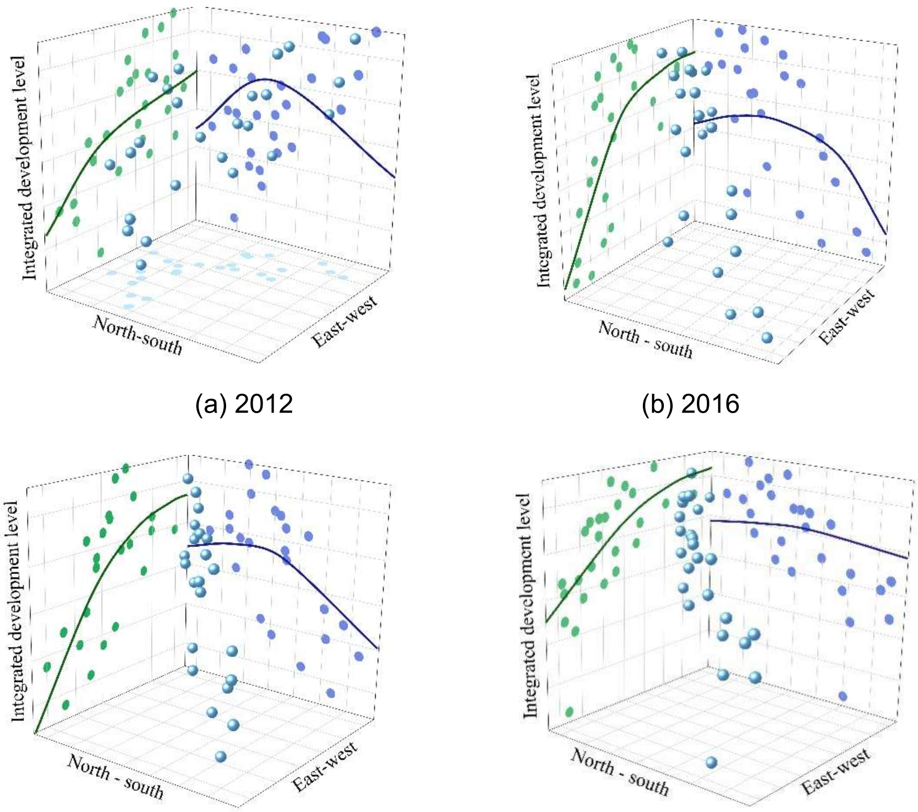
The trend surface analysis of the development level of rural industrial revitalization (Figures a~d indicate 2012-2024, respectively) is shown in Figure 9. From the changing trend of spatial differentiation in each year, the spatial differentiation law of China's rural industrial development from 2012 to 2024 basically remains unchanged, in the east-west direction, the rural industrial development gap among villages in the western, central and eastern regions shows a trend of expanding and then narrowing, and the level of rural industrial development in the eastern and western regions is significantly higher than that of the central region in 2024, with the characteristic of incremental evolution from the west to the east. In the north-south direction, the rural industry development gap among villages in the southern, central and northern regions also shows a trend of expanding and then narrowing, with the rural industry development level in the northern and southern regions significantly increasing relative to that in the central region by 2024, roughly characterized by an incremental evolution from the south to the north.

V. Paths for upgrading rural industrial revitalization

From the experimental results, it can be concluded that the overall effect of China's rural industrial development is better and more significant, but there is still a large upside in some areas, and regional resources should be reasonably deployed to provide supportive policies to continue to strengthen the support for the revitalization of rural industries. In this regard, the article puts forward the following suggestions.

V. A. Nurturing and Strengthening Talent Teams for Rural Industry Revitalization

Talent is a key factor in enhancing the competitiveness of rural industry, and by cultivating and introducing excellent talents, it can promote local advantages in industrial upgrading and innovation. Therefore, the government should constantly innovate the talent training mode, accelerate the training of rural industrial talents, optimize the talent introduction mechanism, and constantly add wisdom to the development of the yellow flower industry. At the same time, we should focus on strengthening the training of village party organization secretaries and new agricultural business leaders, comprehensively improve the quality and literacy of farmers, and nurture and make good use of local talents. Do a good job of education and training of farmers, in order to further enhance the town's overall competitiveness and sustainable development of the yellow flower industry.



(a) 2012 (b) 2016

(c) 2020 (d) 2024

Figure 9: The trend analysis of the development level of rural industry

V. B. Promote large-scale standardized production in the industry

Promoting the deep integration of rural industries requires the participation of the government, enterprises, farmers and other parties to jointly achieve the goals of agricultural efficiency, farmers' income and rural revitalization. Strengthen departmental coordination and up-and-down linkage to form a strong synergy to promote the development of rural specialty industries. Formulate scientific planning, according to the local resource endowment, industrial foundation and market demand, formulate scientific and reasonable industrial development planning, continuously consolidate the foundation of industrial integration, and further promote the integrated development of rural industries.

V. C. Enhancement of inter-subjective linkages of interest

Improving the benefit linkage mechanism is an important means to better protect farmers' interests and promote their income. By enhancing the linkage of interests between farmers and enterprises, it further guarantees stable income for farmers and sound business operation for enterprises, stabilizes the stability of the yellow flower industry chain and improves the ability to prevent and resist risks.

V. D. Accelerating the brand value of agricultural products

The government is an important main body in promoting the branding of agricultural products. In the process of shaping the brand of agricultural products, it is necessary to clarify the direction of its development and supplement it with policy encouragement and support to provide conditions conducive to its development. In the process of accelerating the enhancement of the value of agricultural brands, it is necessary to find the roots of establishing brand confidence, and to establish a distinctive, unique and stable brand image.

VI. Conclusion

The article applies the Chaotic Adaptive Genetic Algorithm to accelerate the TOPSIS model to measure the level of rural industrial development in 31 provinces (autonomous regions and municipalities directly under the central government) of China from 2012 to 2024, and draws research conclusions and relevant recommendations accordingly, so as to better promote the comprehensive revitalization of the countryside.

The fluctuating increase in the comprehensive level of China's rural industrial development from 2012 to 2024 is mainly due to the improvement of the level of information base, while rural capital investment becomes a key factor constraining the sustainable improvement of rural industrial development.

Rural industrial revitalization can be carried out at the levels of cultivating and strengthening the talent team for rural industrial revitalization, promoting industrial scale and standardized production, enhancing the benefit linkage between subjects and accelerating the brand value of agricultural products, with a view to promoting the continuous improvement of rural industrial revitalization in the context of high-quality development.

This study helps to explore more precisely the development of different provinces in China in the construction of digital rural industries, so as to formulate a more scientific and reasonable management model to promote the revitalization of rural industries.

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About the Author

Cheng Shao was born in Bengbu, Anhui Province, China, in 1974. He obtained his master’s degree from Nanchang University in China. Currently, he is a faculty member at the College of Economics and Management, Jiangxi University of Technology. His research interests include business administration and public administration.

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