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Analysis of Regional Differences, Dynamic Evolution and Convergence Characteristics of The Level of Rural Revitalization in China

Wenqing Li, Xiaoxiao Zhou*, Zhongming Ding

School of Finance, Anhui University of Finance and Economics, Bengbu 233030, China
*Corresponding author. Email address: 120160013@aufe.edu.cn

Abstract: To help rural revitalization, it is extremely important to understand the inter-provincial characteristics. This paper uses the entropy value method to measure the comprehensive index of rural revitalization level, and reveals the regional differences and dynamic evolution trend of rural revitalization with the help of Dagum Gini coefficient and kernel density method, and finally uses the β convergence model to test the spatial and temporal convergence. The study finds that the level of rural revitalization is low but tends to increase year by year. Regional differences are the main reason for the differences in rural revitalization, but they are decreasing. There is a polarization phenomenon of inter-provincial rural revitalization level, while there is a tendency for low-level provinces to catch up with high-level provinces. Finally, it is suggested that all kinds of factors should be fully activated to actively promote the coordinated development of regional rural revitalization level.

Keywords: Rural revitalization, Entropy method, Dagum Gini coefficient and decomposition, Kernel density estimation, spatial convergence.

1. Introduction

In recent decades, with the development of urbanization, rural talents and capital elements continue to flow to the cities, and the countryside highlights problems such as hollowing out and environmental deterioration, which makes the urban-rural gap still prominent, specifically in economic, cultural, medical and educational aspects. Nowadays, the unbalanced development of urban and rural areas restricts the development of society. Therefore, Comrade Xi Jinping pointed out that the issue of agriculture, rural areas and farmers is a fundamental issue related to the people's livelihood of the country, and must always take the solution of the "three rural issues" as the top priority of the whole Party and implement the rural revitalization strategy (Xu and Wang 2022)[19]. The revitalization of the countryside is not only an important task, but also a long-term historical task. In this context, it is very important to measure the effectiveness of the rural revitalization strategy, and it is also important to analyze the regional differences, distribution dynamics and evolution patterns of rural revitalization for reference and guidance.

Against this background, the academic circles have been exploring rural revitalization with a high degree of enthusiasm. The current literature mainly focuses on three aspects: the theoretical origin and connotation of rural revitalization, the internal dynamics of rural revitalization, and the level measurement of rural revitalization. First, the theoretical origin and connotation of rural revitalization. Marx and Engels once pointed out that the reason for the gradual decline of the countryside was mainly due to the continuous development of productive forces, and its direct cause was the division of labor and specialization (Max and Engels 1960)[13]. To change this reality, it is necessary to break the original urban-rural structure and division of labor and build an industrial pattern of urban-rural integration and development. The rural revitalization strategy is based on the absorption of Marxist ideas on rural development and urban-rural integration (Zhang et al. 2018a)[26], which the Communist Party of China has adopted as its main idea to guide China's rural development (Zhang et al. 2020)[25]. Whether in China or in other countries, many countries have experienced urban-rural conflicts in the face of industrialization and urbanization, especially when the urbanization level of this country reaches about 50% and the process of rural decline to rural recovery is inevitable (Dong 2017)[7]. To address this issue, the UK and France have implemented rural center village construction, rural revitalization programs and other policy initiatives to cope with the decline of rural areas and to break the urban-rural development dilemma (Liu 2011)[10]. Since the 1970s, East Asian economies such as Japan have proposed village construction, new village construction, and rural regeneration programs in response to rural decline (Zhang et al. 2018a)[26]. Second, the intrinsic power of rural revitalization. In today's digital economy, the integration of digital economy and rural revitalization is widely discussed by the government and the industry (McManus et al. 2012; Salemink et al. 2017; Schmidt and Uriely 2019)[14][16][17], and therefore some scholars believe that digital economy will in turn influence rural revitalization through the intermediary role of industrial upgrading (Cen et al. 2022)[2]. Similarly, financial development will also promote rural revitalization (Zhang 2020; Zhuo et al. 2021)[24][29]. Among them, digital inclusive finance and rural revitalization have been widely studied by scholars. Digital inclusive finance improves the accessibility of rural loans (Corrado 2017; Liu et al 2021)[5][10], and can also give full play to the guiding function of financial resources to promote the integration of inclusive finance with rural environmental protection and green and healthy development, thus giving financial support to green agricultural projects and promoting rural ecological livability (Yang and Fu 2019)[21]. Third, the level of rural revitalization is measured. Based on the connotation of rural

revitalization, scholars have constructed the evaluation system of rural revitalization from different perspectives of economy, politics, society, culture, and ecology (Zhang et al. 2018b; Chen et al. 2021)[3][27], and some scholars have also constructed the evaluation system of rural revitalization from five perspectives of industrial prosperity, ecological livability, rural style civilization, effective governance, and affluent living (Niu et al. 2021; Wang and Xu 2021; Zou et al. 2021; Lu et al. 2022)[12][15][18][30].

In summary, there are more studies on the construction of rural revitalization index system, but not many studies on the dynamic evolution and spatial differences of rural revitalization level. Therefore, the main innovations of this paper are: firstly, it optimizes the rural revitalization indicator system of existing literature to make the assessment results more accurate. Second, because of the different resource endowments of each region, the 31 provinces are divided into four major regions, namely, eastern, central, western, and northeastern, while the Dagum Gini coefficient is used to analyze the overall and regional differences of rural revitalization and the sources of the differences. Thirdly, the kernel density estimation method is used to analyze the dynamic evolution pattern of the distribution of rural revitalization in China. Fourth, the catch-up effect of high and low level provinces is analyzed using the spatial convergence model, so as to make predictions for the future development.

2. Data and Methods

2.1. Comprehensive evaluation index system construction

In 2018, the Central Rural Work Leading Group Office proposed the National Strategic Plan for Rural Revitalization (2018-2022) (the Plan), which is guided by General Secretary Xi Jinping's important remarks on the work of the "three rural areas" and divides the rural revitalization strategy into five aspects: prosperous industry, ecological livability, civilized countryside, effective governance and prosperous living, The Plan is guided by General Secretary Xi Jinping's important statement on the work of "three rural areas", and divides the rural revitalization strategy into five aspects: prosperous industry, pleasant ecology, civilized countryside, effective governance, and prosperous living, with a view to doing a good job in stages. Therefore, based on the studies of Wang Yongyu and Xu Xue (2021), Lu Fengying (2022), Niu Wenhao (2021) and Zou Xiuqing (2021), a rural revitalization index system containing the "five-in-one" objectives and tasks is constructed.

Table 1. China Rural Revitalization Evaluation Index System

Subsystems	Evaluation Indicators	Measurement Method	Unit	Properties
Industrial prosperity	Agricultural labor productivity	Total agricultural output value / rural population	billion yuan / million	+
	Degree of agricultural mechanization	Total power of agricultural machinery	million kilowatts	+
	Degree of agricultural development	Total food production value / rural population	kilograms/person	+
	Rural production benefits	Value added of primary industry/regional GDP	%	+
	Rural Industry Investment	Actual area of productive buildings at the end of the year / rural population	square meter/person	+
	Natural Disaster Situation	Crop damage area	thousand hectares	-
Ecological livability	Renewable Energy Utilization	Total number of solar water heaters / rural population	pcs/person	+
	Chemical substance input	Standardized agricultural fertilizer application + standardized pesticide use	-	-
	Degree of village greening	Greenery coverage	%	+
	Rural household waste treatment	(Number of domestic waste transfer stations + number of special sanitation vehicles and equipment) / Village population	pcs/person	+
	Rural water security	Water penetration rate	%	+
	Rural toilet hygiene situation	Number of public restrooms	pcs	+
Countryside civilization	Traditional Virtues of the Countryside	Population with divorce status in rural areas / Population with various types of marital status in rural areas	‰	-
	Culture and entertainment consumption level	Per capita cultural and entertainment consumption expenditure of rural residents	yuan/person	+
	Educational attainment of farmers	Illiterate population as a percentage of population aged 15 and over	%	+
	Accessibility of cultural and recreational facilities	Number of comprehensive cultural stations in townships / number of townships	%	+
	Accessibility of cultural and recreational activities	Average value of combined coverage of rural radio programs and combined coverage of TV programs	%	+
	Country Folk	Village public building construction input	million yuan	+
Effective governance	Degree of urban-rural income disparity	Rural per capita disposable income / urban per capita disposable income	%	+
	Degree of urban-rural living disparity	Rural per capita consumption expenditure/Urban per capita consumption expenditure	%	+
	Medical level	Number of village health offices + number of village doctors + number of health personnel	pcs	+
	Level of rural poverty	Number of rural residents with minimum living standards	person	-
	Level of rural land governance	Effective irrigated area	thousand hectares	+
	Environmental Health Construction	Environmental health construction input	million yuan	+
Wealthy living	Income level of rural residents	Net income per capita of rural residents	yuan/person	+
	Consumption level of rural residents	Rural retail sales of social goods	billion yuan	+
	Housing level of rural residents	Residential floor space per capita	square meter/person	+
	Engel coefficient	Rural residents' food expenditure/consumption expenditure	%	-
	Public Facility Construction	Utility construction input	million yuan	+

Prosperous industry is the foundation of the economy and the premise for solving all problems in rural areas. Industrial development determines whether it can better attract talents, capital and other elements, and determines the development prospects of the countryside. Industrial prosperity requires in not only producing safe crops, but also demanding crops in quality and quantity, and crops with higher quality and quantity are conducive to the successful transformation of traditional agriculture. Therefore, six indicators such as agricultural labor productivity are chosen to measure industrial prosperity. Ecological livability is the foundation of the environment, combining both rural habitat and ecological environment. This requires focusing on both the environmental quality of rural living, such as rural greenery and garbage situation, and the quality of ecological environment, such as chemical substance pollution. Therefore, six indicators, such as the use of renewable energy, were chosen to reflect ecological livability. The civilization of countryside is the cultural foundation, based on China's thousands of years of farming culture, combined with the modern culture brought by information technology and industrialization. Family style occupies an important position in traditional Chinese virtues, so the rural divorce rate represents the traditional virtues of the countryside. After the formation of modern culture, the entertainment level of rural people has increased. Therefore, six indicators such as the level of cultural and entertainment consumption are used to measure the civilization of rural culture. Effective governance is the foundation of society, which is the combination of autonomy, moral rule and rule of law by grassroots people, which makes the village industry, rural style, ecology and life to achieve good changes. The system, grassroots staff, governance system and other aspects determine the effectiveness of rural governance. The results of effective governance are reflected in rural income, medical investment, environmental investment, etc. Therefore, six indicators such as the degree of urban-rural income disparity are chosen as secondary indicators of effective governance. Affluent living is the goal of people's livelihood. Only when they are well fed and clothed can villagers have the energy and leisure to continue the rural culture, focus on environmental quality, and govern the countryside together. Therefore, 5 indicators such as the income level of rural residents and Engel coefficient are selected to reflect the affluence of life.

3. Research Methodology

3.1. Entropy method

The construction of indicators requires objectivity and should avoid the subjectivity of artificial assignment, so this paper adopts the entropy value method to measure the comprehensive index of China's rural revitalization and the index of each subsystem (Yu and Zhang 2019)[23]. The specific method is as follows:

In the first step, the indicators in the index system are dimensionlessized by the standard method of polar differences. To avoid invalidating the subsequent logarithmic processing, 0.0001 is added to the dimensionless result so as to obtain non-negative values.

$$Z_{\lambda ij} = (x_{\lambda ij} - x_{min})/(x_{max} - x_{min}) + 0.0001 \text{ (Positive indicators)}$$

$$Z_{\lambda ij} = (x_{max} - x_{\lambda ij})/(x_{max} - x_{min}) + 0.0001 \text{ (Negative indicators)}$$

Where, $j = 1, 2, 3, \ldots, n$, denotes the total number of evaluation indicators; $i = 1, 2, 3, \ldots, m$, denotes the total number of evaluation objects; x_{max}、x_{min} are the maximum and minimum values of different indicators j in all evaluation objects; $Z_{\lambda ij}$、$x_{\lambda ij}$ are the indicator values of different indicators i after dimensionless and before dimensionless.

In the second step, the metrics are normalized.

$$P_{\lambda ij} = Z_{\lambda ij} / \sum_{\lambda=1}^{h} \sum_{i=1}^{m} Z_{\lambda ij}$$

In the third step, the entropy value of each indicator is calculated.

$$E_j = -k \sum_{\lambda=1}^{h} \sum_{i=1}^{m} P_{\lambda ij} ln P_{\lambda ij}$$

Where $k = -1/\ln(h \times m)$ and h denotes the total number of years.

In the fourth step, the redundancy of the entropy value of each index is calculated.

$$D_j = 1 - E_j$$

In the fifth step, the weights of each indicator are calculated.

$$W_j = D_j / \sum_{j=1}^{n} D_j$$

In the sixth step, the composite score for each province is calculated for each year.

$$C_{\lambda i} = \sum_{j=1}^{n} W_j Z_{\lambda ij}$$

3.2. Dagum Gini coefficient and its decomposition

Dagum proposed the Dagum Gini coefficient in 1997 to improve on the shortcomings of the traditional Gini coefficient. Specifically, the Gini coefficient was decomposed into three components: intra-subgroup variation, net inter-subgroup variation, and hyper-variance density, which solved the problem of having overlapping components between sample subgroups and was widely used in the study. The specific methods are as follows (Dagum 1998; Chen et al. 2017; Han 2020) [4][6][8]:

The first step is the overall Gini coefficient.

$$G = \left(\sum_{j=1}^{k} \sum_{h=1}^{k} \sum_{i=1}^{n_j} \sum_{r=1}^{n_h} |y_{ji} - y_{hr}|\right) \Big/ 2n^2 \bar{y}$$

$$G \equiv G_w + G_{nb} + G_t$$

Where the overall is divided into k groups; y_{ji} and y_{hr} denote the composite index of rural revitalization level of the i(r) provinces in group j(h), respectively; n denotes the total number of provinces; $\bar{y}$ denotes the average of the composite index of rural revitalization level of all provinces.

G_w denotes the contribution of within-subgroup variation to the overall Gini coefficient; G_{nb} denotes the net contribution of between-subgroup variation to the overall Gini coefficient; and G_t denotes the contribution of hypervariable density to the overall Gini coefficient.

In the second step, the Gini coefficient within subgroups.

$$G_{jj} = \left(\sum_{i=1}^{n_j} \sum_{r=1}^{n_j} |y_{ji} - y_{jr}|\right) \Big/ 2n_j^2 \bar{y_j}$$

In the third step, the contribution of intra-subgroup differences to the overall Gini coefficient.

$$G_w = \sum_{i=1}^{n_j} G_{jj} P_j S_j$$

Where $P_j \equiv n_j/n$ denotes the proportion of provinces in the jth region to all provinces; $S_j = n_j\bar{y}_j/n\bar{y}$ denotes the proportion of the sum of rural revitalization levels in the jth region to the sum of rural revitalization levels in all cities.

In the fourth step, the Gini coefficient between subgroup h and subgroup j.

$$G_{jh} = \left(\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}|y_{ji} - y_{hr}|\right)\Big/ n_j n_h(\overline{y_j} + \overline{y_h})$$

In the fifth step, the net contribution of inter-subgroup differences to the overall Gini coefficient.

$$G_{nb} = \sum_{j=2}^{k}\sum_{h=1}^{j-1} G_{jh}(P_j S_h + P_h S_j) D_{jh}$$

In the sixth step, the contribution of hypervariable density to the overall Gini coefficient.

$$G_t = \sum_{j=2}^{k}\sum_{h=1}^{j-1} G_{jh}(P_j S_h + P_h S_j)(1 - D_{jh})$$

Among them,

$$D_{jh} = \frac{d_{jh} - p_{jh}}{d_{jh} + p_{jh}}$$

$$d_{jh} = \int_0^{\infty} dF_j(y) \int_0^{y} (y - x) dF_h(x)$$

$$p_{jh} = \int_0^{\infty} dF_h(y) \int_0^{y} (y - x) dF_j(x)$$

3.3. Kernel density estimation method

Kernel density estimation is a continuous density curve to describe the distribution characteristics of the level of rural revitalization in the province, which can be intuitively understood as a continuous histogram.

The calculation formula is:

$$f(x) = \frac{1}{Nh}\sum_{i=1}^{N} K\left(\frac{X_i - \bar{x}}{h}\right)$$

Where N is the number of observations; X_i is the independent identically distributed observations; $\bar{x}$ is the observation mean; and h is the bandwidth. In this paper, the Gaussian kernel density is used for distribution dynamics analysis estimation (Lee et al. 2017; Yao et al. 2022)[9][22], and the estimation formula is:

$$K(x) = \frac{1}{\sqrt{2\pi}} e^{\left(-\frac{x^2}{2}\right)}$$

3.4. Spatial β convergence model

This paper adopts β convergence to examine the development evolution trend of rural revitalization level in different provinces in China. β convergence was first proposed in the neoclassical growth concept, and in this paper, it means that as time advances, provinces with lower levels of rural revitalization have higher increases to catch up with provinces with higher levels of rural revitalization, so that the gap between regions of various levels keeps narrowing and reaches the same steady-state level. β convergence is generally divided into absolute β convergence and conditional β convergence. Absolute β convergence refers to the tendency of convergence of rural revitalization levels between provinces without considering a series of factors that have important effects on rural revitalization levels (Zhang et al. 2017; Yang et al. 2021)[20][28].

Considering the possible spatial correlation characteristics of rural revitalization level, spatial panel models are thus introduced. The common spatial econometric models include spatial lag model (SAR), spatial error model (SEM), spatial Durbin model (SDM), etc. The spatial absolute β convergence model is as follows:

$$SAR: \ln\left(\frac{RRS_{i,t+1}}{RRS_{it}}\right) = \alpha + \beta ln(RRS_{it}) + \rho\sum_{j=1}^{n}\omega_{ij} ln\left(\frac{RRS_{i,t+1}}{RRS_{it}}\right) + \mu_i + \eta_t + \varepsilon_{it}$$

$$SEM: \ln\left(\frac{RRS_{i,t+1}}{RRS_{it}}\right) = \alpha + \beta ln(RRS_{it}) + \mu_i + \eta_t + u_{it} \quad u_{it} = \lambda\sum_{j=1}^{n}\omega_{ij} u_{it} + \varepsilon_{it}$$

$$SDM: \ln\left(\frac{RRS_{i,t+1}}{RRS_{it}}\right) = \alpha + \beta ln(RRS_{it}) + \rho\sum_{j=1}^{n}\omega_{ij} ln\left(\frac{RRS_{i,t+1}}{RRS_{it}}\right) + \gamma\sum_{j=1}^{n}\omega_{ij} ln(RRS_{it}) + \mu_i + \eta_t + \varepsilon_{it}$$

Where ρ is the spatial lag coefficient, which indicates the influence of the growth rate of rural revitalization level in neighboring provinces on this province, λ is the spatial error coefficient, which indicates the spatial effect present in the random disturbance term; γ is the spatial lag coefficient of the independent variable, which indicates the influence of the rural revitalization level in neighboring provinces. ω_{ij} is the spatial weight, and in this paper, in order to avoid the endogenous interference of economic and social distance on the model, the geospatial weight is constructed here matrix.

The conditional β convergence model adds a series of control variables to the absolute β convergence model to discuss whether the level of rural revitalization has a convergence trend under a series of conditions that have important influences on the level of rural revitalization, corresponding to the absolute β convergence model, and the conditional β convergence model is as follows:

$$SAR: \ln\left(\frac{RRS_{i,t+1}}{RRS_{it}}\right) = \alpha + \beta ln(RRS_{it}) + \rho\sum_{j=1}^{n}\omega_{ij} ln\left(\frac{RRS_{i,t+1}}{RRS_{it}}\right) + \delta X_{i,t+1} + \mu_i + \eta_t + \varepsilon_{it}$$

$$SEM: \ln\left(\frac{RRS_{i,t+1}}{RRS_{it}}\right) = \alpha + \beta ln(RRS_{it}) + \delta X_{i,t+1} + \mu_i + \eta_t + u_{it} \quad u_{it} = \lambda\sum_{j=1}^{n}\omega_{ij} u_{it} + \varepsilon_{it}$$

$$SDM: \ln\left(\frac{RRS_{i,t+1}}{RRS_{it}}\right) = \alpha + \beta ln(RRS_{it}) + \rho\sum_{j=1}^{n}\omega_{ij} ln\left(\frac{RRS_{i,t+1}}{RRS_{it}}\right) +$$

$$\gamma \sum_{j=1}^{n} \omega_{ij} ln(RRS_{it}) + \delta X_{i,t+1} + \mu_i + \eta_t + \varepsilon_{it}$$

Where $X_{i,t+1}$ is a set of control variables affecting the level of rural revitalization, and δ is a parameter vector. The selected control variables are information convenience (IC), i.e. rural delivery routes; energy intensity (EN), i.e. rural electricity generation; foreign investment intensity (FDI), i.e. total import and export of foreign-invested enterprises; and ecological importance (ECO), i.e. investment completed in the current year for ecological construction and protection.

3.5. Data source

Due to the limited data, 31 provinces from 2010 to 2020 are selected as observation samples in this paper, and the 31 provinces are divided into four major regions according to geographical location: eastern, central, western, and northeastern regions, as shown in Figure 1. research data are mainly obtained from China Statistical Yearbook, China Statistical Yearbook of Urban and Rural Construction, China Statistical Yearbook of Rural Areas, and China Statistical Yearbook of Urban and Rural Areas, and for individual missing data, the interpolation method is used for processing.

Figure 1. Four regional provinces distribution

4. Empirical Analysis

4.1. Evaluation Analysis of Comprehensive Indicators for Rural Revitalization

Fig.2 shows the trends of the comprehensive index and sub-system index of rural revitalization from 2010 to 2020. According to the measurement results, there are two characteristics of the comprehensive index of rural revitalization in China as follows. First, the overall comprehensive index is at a low level, and the comprehensive index from 2010 to 2020 is below 0.45. Second, the comprehensive index of rural revitalization is increasing over time, from 0.237 in 2010 to 0.412 in 2020, with an increase of 73.840%. Based on this, in 2021, the central government proposes to comprehensively promote rural revitalization and promulgate and implement the Law on Promoting Rural Revitalization, which means that the rural revitalization strategy will continue to advance on the original effectiveness and has become an and its important task.

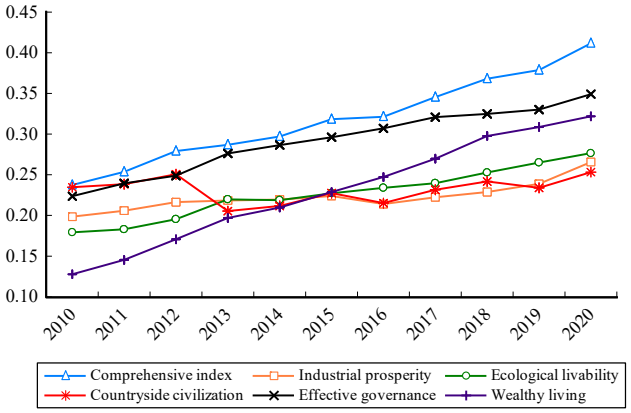

Figure 2. Trends of Rural Revitalization Composite Index and Subsystem Index from 2010 to 2020

From the results of the five subsystems measurement: first, the industrial prosperity index does not fluctuate much during the examination period, but is in an upward trend overall. In 2018-2020, the rising trend is more obvious, with an increase of 16.157%; second, the ecological livability index increases year by year, with a more obvious growth trend from 2010-2013 and a slow growth from 2014-2020; third, the countryside civilization index is growing at the end of the survey period compared with the beginning of the survey period, but the fluctuation of the whole survey period is first growth, then a sudden and sharp decline, and then a slow growth, with an overall increase of 7.660%. Fourth, the index of effective governance increases year by year, from 0.224 in 2010 to 0.349 in 2020; fifth, the index of living affluence grows most obviously, from 0.128 in 2010 to 0.322 in 2020. Overall, all five subsystems have increased. Among them, the index of effective governance is the largest, indicating that the level of governance in China's countryside is better, which is not only reflected in the Party's autonomy, moral governance and rule of law have achieved better results, but also in various aspects such as medical care, economy and ecology. The smallest industrial prosperity index indicates that the current industrial level of China's countryside needs to be improved, which requires corresponding changes according to the local agricultural base, combined with the actual situation. For example, develop some special industries, open up new industries, combine the characteristics of the countryside as a whole to form a complete industrial chain, and accelerate the realization of a new pattern of integrated development of one, two and three industries.

5. Analysis of Regional Differences in Rural Revitalization

This paper mainly adopts the Dagum Gini coefficient decomposition method to calculate the total variation, intra-regional variation, net contribution of inter-regional variation and inter-regional hypervariable density of rural revitalization level. The aim is to investigate where the regional differences in the level of rural revitalization and the integral differences lie.

5.1. Intra-regional differences

Fig.3 it shows the differences in the level of rural development in China in general and among regions. In terms of the overall trend of internal differences in the revitalization of rural areas in China, the regional differences in the revitalization of rural areas in China show a decreasing trend,

with the Gini coefficient decreasing from 0.244 in 2010 to 0.198 in 2020, with an average annual decrease of 2.030%. Specifically, the Gini coefficient shows a steady decreasing trend from 2010 to 2012 and from 2013 to 2020, with a small increase in 2012. the increase in 2012 is mainly due to the fluctuation of the level of rural revitalization in some provinces, such as Hebei, Jiangsu, Yunnan, Xinjiang and other provinces. The Gini coefficients of regional differences in eastern, western, central and northeastern China show a change from large to small. The intra-regional differences in the central and northeastern regions are more stable in comparison and have been at a low level. The intra-regional differences are slightly higher in the western region compared to the central and northeastern regions, but overall the differences are also gradually decreasing. The Gini coefficient in the eastern region is relatively high and tends to increase in the later period compared to the beginning of the study period.

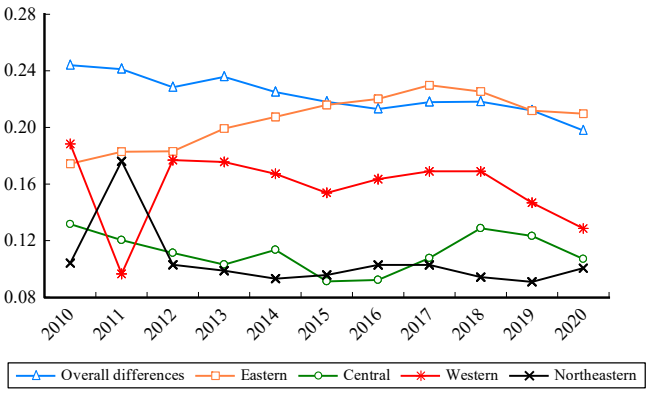

Figure 3. Intra-regional variation in composite index

All in all, the internal differences of rural revitalization in the four major regions show a pattern of Eastern > Western > Central > Northeastern. By analyzing the comprehensive index of rural revitalization in each province, we can see that there are huge gaps in rural revitalization in the eastern provinces. In 2020, Shandong, Jiangsu and Zhejiang have a comprehensive index of rural revitalization greater than 0.6 and become the "first echelon", Hebei, Guangdong and Fujian with the comprehensive index around 0.5 form the "second echelon", and Shanghai, Henan, Beijing and Tianjin with the comprehensive index less than 0.4 are the "third echelon ". The internal differences in the eastern region are the direct reason for the large differences in rural revitalization. The internal differences in northeastern China are relatively small, as the differences in the level of rural revitalization in Liaoning, Jilin and Heilongjiang are not too big, all between 0.1 and 0.4. And the general trend is increasing.

5.2. Inter-regional differences

Fig.4 illustrates the regional differences in the level of rural revitalization in China and the changes in trends. The change in the inter-regional Gini coefficient shows a decreasing trend in all regions, with the largest decrease between the east and the west, where the level of rural revitalization is much higher than that in the west. The rapid development of the level of rural revitalization in western China has led to a strong catch-up trend, resulting in a significant decrease in the Gini coefficient between the east and the west. Specifically, the inter-regional Gini coefficient decreases from 0.178 in 2010 to 0.175 in 2020, or 1.248%. The East-West inter-regional Gini coefficient decreases from 0.343 in 2010 to 0.238 in 2020, i.e., a decrease of 30.635%. The East-Northeast inter-regional Gini coefficient decreases from 0.357 in 2010 to 0.304 in 2020, a decrease of 14.960%. The Gini coefficient between the central and western regions decreases to 28.262%, the central and northeastern regions decreases to 1.872%, and the western and northeastern regions decreases to 1.583%. This indicates that the implementation of the strategy of rural revitalization will gradually reduce the regional disparity in all regions, and rural revitalization begins to develop in a comprehensive and coordinated manner.

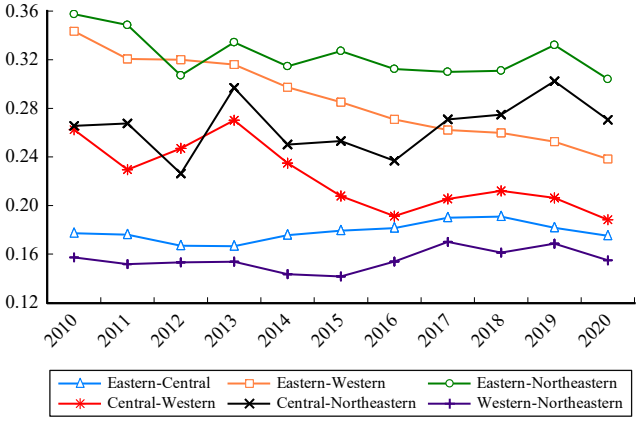

Figure 4. Inter-regional variation in composite index

5.3. Sources and contribution of regional differences

Table 2 shows the regional disparities in the level of rural revitalization nationwide, and the contribution rates of the sources of these disparities. According to the trend of contribution rate of rural revitalization nationwide, the contribution rate of intra-regional differences shows an overall upward change, while the contribution rate of inter-regional differences is slowly decreasing and the contribution rate of super-variable density is increasing year after year. As observed from the contribution rate value, the contribution rate of inter-regional differences is the highest with an average contribution rate of 59.795%, the average contribution rate of intra-regional differences is 23.297%, and the average contribution rate of super-variable density is the lowest with only 16.908%. Therefore, we can see that the main reason for the formation of regional differences in rural revitalization is inter-regional differences, which may be due to: first, the innate differences in resource endowment. For example, coastal areas in the east are more convenient for foreign trade and commercial exchanges; while western areas have vast land and are more suitable for animal husbandry, and are economically disadvantaged compared to the east, which is the main reason for the difference in rural revitalization. Second, the trend of talent and population flow. Population loss leads to the decline of rural areas, and "people" are the main resource of rural areas. The population in eastern China is large and concentrated, while the population in western China is relatively small and scattered. The abundant human resources in the east are sufficient to support regional development. Third, financial and capital investment. In the first stage of implementing rural revitalization, government financial investment is the basic guarantee and main driving force to support the promotion of rural revitalization. The developed economy of the eastern region has led to rapid growth of fiscal revenue, thus strongly supporting rural infrastructure construction and environmental management. In contrast, financial resources

in other regions are relatively weak, local financial investment is insufficient, and rural revitalization is developing slowly. Meanwhile, under the role of allocating resources, more funds and social capital are invested in the eastern regions, which largely promotes the development of rural revitalization in the eastern regions. Therefore, in order to solve the problems such as regional disparity in rural development, attention should be paid to narrowing regional disparity. At present, in a critical stage of promoting the comprehensive development of rural revitalization, governments at all levels should fully carry out comprehensive coordination work, do a good job of integrated planning, pay attention to synergy in the process of rural revitalization regions while paying attention to their correlation and wholeness, and promote the coordinated development of rural revitalization among regions.

Table 2. The results of measuring the sources and contributions of rural revitalization development differences

Year	Intra-regional differences		Inter-regional differences		Hypervariable Density	
	Source	Contribution rate	Source	Contribution rate	Source	Contribution rate
2010	0.0510	20.9247	0.1681	68.9020	0.0248	10.1733
2011	0.0501	20.7874	0.1665	69.0310	0.0246	10.1816
2012	0.0500	21.9188	0.1503	65.8391	0.0280	12.2421
2013	0.0514	21.7869	0.1501	63.6621	0.0343	14.5509
2014	0.0525	23.3235	0.1383	61.4780	0.0342	15.1985
2015	0.0515	23.6015	0.1360	62.3851	0.0306	14.0134
2016	0.0532	24.9772	0.1226	57.5694	0.0372	17.4533
2017	0.0553	25.3999	0.1139	52.2983	0.0486	22.3018
2018	0.0555	25.4538	0.1094	50.1519	0.0532	24.3943
2019	0.0510	24.0490	0.1151	54.3373	0.0458	21.6138
2020	0.0476	24.0454	0.1030	52.0944	0.0472	23.8602

5.4. Analysis of the distribution dynamics and evolution of rural revitalization

This paper uses kernel density estimation to present the overall shape and dynamic evolution characteristics of the level of rural revitalization in China, and the results are shown in Fig.5. In terms of the movement of wave peaks over time, the main peak of the kernel density curve of the national comprehensive index of rural revitalization level shifts significantly to the right, which shows that the overall trend of rural revitalization level is rising; in terms of the height and width of wave peaks, the wave peaks slowly move down and become wider, and there is an obvious right trailing phenomenon at the later stage, although the overall difference is decreasing, the extreme values of individual provinces affect the state of wave peaks, such as Jiangsu, Guangdong, and Shandong; in terms of polarization, the rural revitalization development level has small side peaks, and the lower side peak peaks indicate that there is a slight polarization trend in the rural revitalization development level. In conclusion, the national rural revitalization level is improving and slightly polarized. Therefore, in the process of implementing the rural revitalization policy, China should pay attention to the perspective of the whole country, encourage the better areas to help other backward and difficult areas, and finally realize the common improvement of rural revitalization level.

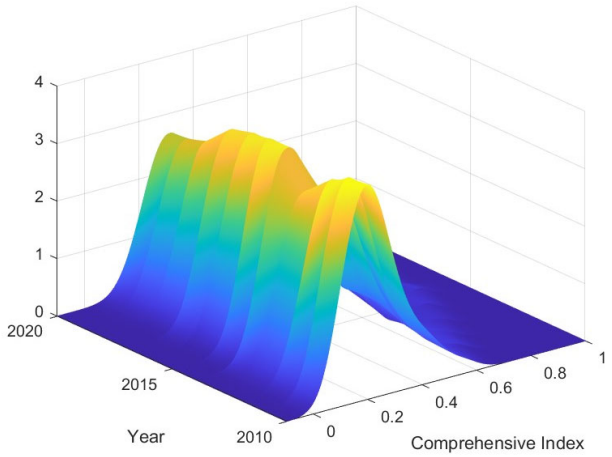

Figure 5. Distribution dynamics of the composite index of rural revitalization

6. Spatial Convergence Analysis of Rural Revitalization

6.1. Spatial autocorrelation analysis

To study the spatial correlation and the degree of correlation of the level of rural revitalization in China, this paper conducts an empirical study with the Moran index in spatial econometrics. The Moran index can be regarded as the product sum of the rural revitalization level of provinces and fluctuates between -1 and 1 (Cao et al. 2022)[1]. If the Moran index is greater than 0, it means that there is a positive correlation in the spatial aggregation of rural revitalization level, and a larger value means a stronger positive correlation

in the spatial distribution; if the value is less than 0, it means that there is a negative correlation in the spatial distribution of rural revitalization level, and a smaller value means a greater dispersion of each spatial unit of the spatial distribution; if its value is 0, it means that the spatial distribution of rural revitalization level is approximately The spatial correlation between provinces does not exist.

Table 3 reflects the test results of the Moran index. The Moran indexes of rural revitalization levels from 2010 to 2020 are all greater than 0, and they all pass the significance level test, which indicates that there is a strong spatial autocorrelation between the rural revitalization levels of each province.

Table 3. The results of Moran's I test

Year	Moran's I	Z	P
2010	0.139	4.501	0.000
2011	0.130	4.312	0.000
2012	0.128	4.270	0.000
2013	0.099	3.512	0.000
2014	0.080	3.083	0.002
2015	0.065	2.684	0.007
2016	0.059	2.507	0.012
2017	0.055	2.342	0.019
2018	0.068	2.650	0.008
2019	0.085	3.080	0.002
2020	0.085	3.071	0.002

6.2. β convergence test

Regarding the selection of models, the initial model is subjected to OLS regression in this paper, and the spatial autocorrelation is tested using LM statistics, and there exists spatial autocorrelation, and at least one of SAR and SEM models holds. Next, the SDM model is established and the Wald test and LR test are used to determine whether the models degenerate to SAR and SEM. after the tests, the SAR model is used as the main model for considering the spatial correlation convergence test and the OLS model is used as the main model for not considering the spatial correlation convergence test in this paper. In addition, based on the Hausman test results, the fixed-effects model is used in this paper.

Table 4 shows that the regression coefficients of models 1 to 4 are significantly negative, which implies that the level of rural revitalization in China shows significant convergence from 2010 to 2020. For absolute convergence, the convergence speed of models 1 and 3 (0.028, 0.021) is greater than that of conditional convergence models 2 and 4 (0.032, 0.021), indicating that the convergence speed of rural revitalization level will be slightly reduced after adding control variables regardless of the existence of spatial correlation, indicating that the control variables are appropriately selected and the test results are informative. When spatial association is considered, the absolute and conditional convergence speeds (0.021, 0.021) are smaller than the classical convergence speed (0.028, 0.032), respectively, indicating that the model may lead to biased estimation results if spatial association is ignored, thus proving that the empirical model of this paper is chosen reasonably.

Table 4 β convergence test regression results

Variables	Disregard spatial association		Consider spatial association	
	Absolute convergence (OLS) (Model 1)	Conditional convergence (OLS) (Model 2)	Absolute convergence (SAR) (Model 3)	Conditional convergence (SAR) (Model 4)
β	-0.262**	-0.300***	-0.206***	-0.206***
ρ	-	-	0.768***	0.773***
Control variables	No	Yes	No	Yes
Province FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Convergence speed	0.028	0.032	0.021	0.021
Convergence period	25.100	21.377	33.054	33.054

7. Conclusions and Recommendations

Based on the "rural revitalization strategy", this paper constructs a comprehensive index system of 29 indicators to measure the level of rural revitalization in 31 provinces in China from 2010 to 2020. The kernel density estimation was used to show the distribution dynamics and evolution of rural revitalization level; the β convergence model was used to analyze the convergence of rural revitalization level. The following conclusions are drawn:

First, in general, the level of rural revitalization in China is low, but the overall level is increasing year by year. From the five subsystems, each subsystem index is gradually increasing, with the highest level of effective governance and the lowest level of industrial prosperity. Second, on the whole, the inter-provincial rural revitalization differences in China are narrowing, and the ranking of rural revitalization level in the four major regions roughly shows East > West > Central > Northeast, and the inter-regional differences in each region are basically decreasing, but the inter-regional differences are the most important factor leading to the regional differences in rural revitalization. Thirdly, the main peak of the kernel density curve of rural revitalization level nationwide shifts to the right, the height of the kernel density curve wave decreases and the width of the wave increases during the sample period, and there is an obvious right trailing phenomenon, while there are small side peaks and the peak value of the side peaks is extremely low, indicating that the level of rural revitalization is increasing year by year and there is a polarization phenomenon. Fourth, there is an obvious catch-up effect in 31 provinces across the country, and there are absolute β convergence and conditional β convergence.

Based on the findings of this paper, the following policy insights were obtained:

First, ensure that the factor endowment empowers the countryside and injects new blood for revitalization. The improvement of the level of rural revitalization benefits from the three aspects of talent, land and capital. Talent is the key to rural revitalization, and the first thing is to stimulate the endogenous power of talent. Multiple channels should be opened to solicit farmers' opinions, understand their real

needs, and conduct transparent rural governance so that the farmers can participate in it. The second thing is to attract talents, and a variety of funds can be set up to motivate them to start their own businesses in the countryside. While ensuring that local talents will not be lost, high-quality foreign talents will be attracted to build the countryside and help revitalize the countryside together. Land is the resource for rural revitalization. To ensure the maximum utilization of land, activating land elements should improve the land transfer mechanism and encourage farmers to flexibly use land management rights and build collective land. Capital can inject new blood into rural revitalization. The government can establish financial funds or encourage social capital to flow into the countryside, while financial institutions can be encouraged to import capital into the countryside to realize the combination of financial system and rural revitalization.

Second, to promote the coordinated and comprehensive development of regional rural revitalization levels. The current differences in rural revitalization mainly come from the differences in geographical locations of the four major regions, so narrowing the differences between regions is the key to achieving nationwide rural revitalization. Since the ecological level, natural resources and human resources of each region are very different, governments at all levels should make appropriate plans according to local conditions, instead of implementing a "one-size-fits-all" policy. Governments at all levels should make appropriate plans according to local conditions, rather than implementing one-size-fits-all policies. They can combine multiple industries, such as "tourism + agriculture", "animal husbandry + agriculture", "financial industry + agriculture", "smart agriculture "etc., using their own advantages to develop agriculture can achieve twice the result with half the effort.

8. Statements & Declarations

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Availability of data and material: The datasets used or analyzed during the current study are available from the yearbooks or the corresponding author on reasonable request.

Code availability: Not applicable.

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