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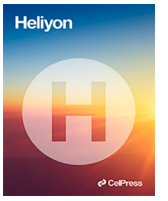

Research article

Rural revitalization in China: Measurement indicators, regional differences and dynamic evolution

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ABSTRACT

It is crucial to scientifically assess China's rural revitalization and grasp its evolution laws. This paper constructs an indicator system to measure the level of rural revitalization in China from 2011 to 2021 using the entropy weight method. Then, we explore the spatial and temporal divergence and dynamic evolutionary characteristics of rural revitalization using the Dagum Gini coefficient and Kernel density. We found that the level of rural revitalization in China is low but fluctuating and increasing. Regionally, eastern China scores higher than central, western and northeastern China. In terms of dimensions, ecological livability scores are higher than prosperous industry, effective governance, affluent living and civilized countryside in that order. The regional differences in the level of rural revitalization are mainly reflected between regions, especially between eastern and western China, but the gap between regions is narrowing year by year. And the results of the Kernel density show that the level of rural revitalization in China shows a slow and balanced growth, but the eastern China shows a polarization growth. These findings can provide a comprehensive and objective outline of the advantages and shortcomings of rural revitalization development in China, and provide a policy reference for the comprehensive and stable promotion of rural revitalization construction.

1. Introduction

Rural revitalization is the most important strategic plan in China in the next 30 years. China is a large agricultural country, the comprehensive construction of a socialist modernization of the country, the most difficult and heavy task is still in the countryside [1]. The strategy of rural revitalization in China was proposed by President Jinping Xi in October 2017. He emphasized that China must always prioritize solving the problems of agriculture, rural, and farmers as the top priority of the entire government's work. Subsequently, in the government report, it was clearly pointed out that China should prioritize the development of agriculture, and promote this strategy in accordance with the overall goals of prosperous industry, ecological livability, civilized countryside, affluent living and effective governance. So, what is the current status of China's rural revitalization development? Measuring the level of rural revitalization in China and then comprehensively, objectively, and truly grasping the advantages and disadvantages of regional development is a fundamental work related to the overall situation.

The existing literature has actively explored the scientific connotation and measurement methods of rural revitalization, and fruitful academic results have emerged. Scholars believe that the countryside is a regional complex with natural, social and economic

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characteristics, which has multiple functions such as production, living, ecology and culture, and is the main space constituting human activities ([2]). Rural revitalization is essentially the reconstruction and upgrading of rural society, economic forms and ecology ([3]). Under the guidance of the concept of reconstructing the countryside, the comprehensive implementation of rural revitalization in response to the increasingly serious problem of "rural diseases" is not only a major strategy for promoting urban-rural integration and the sustainable development of the countryside, but also an indispensable requirement for promoting the modernization of the countryside [4]. In the construction of the index system for measuring rural revitalization, most scholars take “prosperous industry, ecological livability, civilized countryside, affluent living, and effective governance” as the common primary index based on the development goal of rural revitalization, but the differences in the selection of secondary measurement indexes are greater [5,6]. In terms of measurement methods, scholars generally use the entropy weight method, and a few scholars use empirical methods such as hierarchical analysis and principal component analysis [5,7,8]. In terms of research region selection, scholars has tried to expand to multiple dimensions such as the country, provinces, counties, and villages [5,9].

In general, the existing literature has the following characteristics: First, most scholars measure the selection of indicators on the basis of inadequate, especially the selection of secondary indicators is not comprehensive. This will lead to a low accuracy of the measurement results of the level of rural revitalization in China. Secondly, there is a lack of research on regional differences and time dynamic evolution of rural revitalization, which cannot better grasp the detailed information on the development of rural revitalization in China, and there is a lack of vertical comparison in time dimension and horizontal comparison in spatial dimension among regions to provide guidance on differentiated practice policies. Therefore, this study will construct an indicator system from five dimensions: Prosperous industry, ecological livability, civilized countryside, affluent living, and effective governance, measure the level of rural revitalization in China from 2011 to 2021 using the entropy weight method, and explore the spatial and temporal divergence and dynamic evolutionary characteristics of the level of rural revitalization using the Dagum Gini coefficient and Kernel density. Different from previous studies on China’s rural revitalization level at the provincial level, this paper further analyzes the characteristics of spatial and temporal differences in rural revitalization and their influencing factors according to China’s four major regional divisions, so as to provide differentiated policy recommendations.

The main contributions of this paper are as follows: First, based on the five primary indicators of prosperous industry, ecological livability, civilized countryside, effective governance and affluent living, the information of the authoritative database on the official website of the Chinese government was extensively collected, and 32 secondary indicators were finally obtained to build a more comprehensive index system for rural revitalization ([9,10]). Secondly, Arcgis software is used to systematically compare and analyze

Table 1
The measurement index system of rural revitalization.

Primary indicators	Secondary indicators	Indicator measurement method
Prosperous industry	Investment intensity	Share of agricultural investment in total fixed capital investment (excluding farmers)
	Large-scale agriculture	Main business income of agricultural product processing enterprises above designated size (Billion)
	Open to the public	Total foreign investment in agriculture/Total agricultural output
	Exports	Agricultural exports/Total agricultural output
	Capital factors	Number of listed companies in agriculture/Total number of listed companies
	Labor factors	Number of people in agriculture/Total agricultural output
	Service industry	Value added of rural services/Value added of total agricultural output
Ecological Livability	Soil conservation	Soil and water management area
	Fertilizers	Fertilizer application discounted amount
	Pesticide	Pesticide utilization/Output of major crop products
	Agricultural film	Area covered by agricultural film/Cropland area
	Straw harmless	Comprehensive utilization rate of straw
	Forest cover rate	Rural forest cover rate
	Ammonia emission rate	Agricultural ammonia emissions/Gross output value of agriculture, forestry, livestock and fisheries
	COD emission rate	Agricultural chemical oxygen demand emissions/Gross output value of agriculture, forestry, livestock and fisheries
Civilized countryside	Intangible cultural heritage	Intangible Cultural Heritage of Agriculture
	Geographical indication	Number of agricultural geographical indications above national level
	Cultural preservation	Amount invested by provinces (municipalities and districts) in the protection of rural historical and cultural villages
	Cultural-tourism combination	Gross income from rural tourism/Total agricultural output
	Cultural creative capacities	Number of cultural creations at provincial level and above in rural areas
Affluent living	Per capita grain production	Total Grain Production/Current year resident population
	Urban-rural income ratio	Per capita net income of farmers/Per capita net income of urban residents
	Rural living standards	Engel coefficient of rural households
	Rural income level	Per capita disposable income of rural residents
Effective Governance	Rural transportation	Road Density
	Rural education	Average number of years of education for rural population (year)
	Medical conditions	Rural cooperative medical insurance rate and the number of doctors and hospital beds per capita in townships
	Innovation output	Contribution rate of agricultural science and technology
	Technological achievements	Number of agriculture-related patents/Total patents
	Agricultural technology market	Agricultural-related technology transactions/total agricultural output

the level of rural revitalization in 31 Chinese provinces from different time points, and draw a more detailed and intuitive visualization map by dimension. Third, the Dagum Gini coefficient and its decomposition method are used to examine the regional differences in China's rural revitalization level and its sources, and the Kernel density function is further used to explore the dynamic evolution of the distribution of rural revitalization level in the whole country and the four major regions, which is also the core innovation of this paper. The findings of this paper can provide a clearer and more intuitive understanding of the current situation of rural revitalization development in each province, so as to comprehensively and objectively outline the strengths and shortcomings of rural revitalization development in each region of China, and then provide policy references to comprehensively and stably promote the construction of rural revitalization.

2. Materials and methods

2.1. Measurements of rural revitalization

A scientific indicator system is the key to accurately measuring rural revitalization. Based on the authoritative policy texts and the consensus of scholars in China, we also construct the index system of measuring the level of rural revitalization in five dimensions: Prosperous industry, ecological livability, civilized countryside, affluent living, and effective governance (Table 1). Industrial revitalization is the foundation of rural revitalization, and only through industrial revitalization can we provide the material foundation and economic support for rural development. Talent revitalization is the key to the revitalization of the countryside, only with enough talent can we provide intellectual support and technical guarantee for the development of the countryside. Cultural revitalization is the soul of rural revitalization, only by strengthening the cultural construction of the countryside, we can provide spiritual impetus and cultural support for the development of the countryside. Ecological revitalization is an important part of rural revitalization. Only by protecting the ecological environment of the countryside can we provide a sustainable basis for rural development. Organizational revitalization is the guarantee of rural revitalization, only by strengthening the construction of rural organizations can we provide a strong organizational guarantee for the development of the countryside. In short, the five revitalization is an interlinked, mutually reinforcing organic whole, only by realizing the synergistic development of the five revitalization, can we realize the comprehensive revitalization of the countryside. And the following optimizations were made in the selection of secondary indicators.

(1) Prosperous industry: Investment intensity, large-scale agriculture, open to the public, exports, and added value of tertiary industries such as capital factors, labor factors, and services industry. The current literature still mainly measures the traditional perspective of large-scale agriculture and rural labor force, while this paper focuses on how to improve the level of agricultural industrialization from the perspective of making up for the shortcomings, and through this comprehensive measure of the level of industrial development, which is more in line with the definition of modern agriculture [11].
(2) Ecological livability: Soil conservation, fertilizers, pesticide, agricultural film, straw harmlessness, forest cover rate, ammonia emission rate, COD emission rate. While previous studies have focused only on the natural environment [12], this paper expands its connotation. Among them, soil conservation is used to measure the level of rural ecosystem management. Fertilizer, pesticide, agricultural film, and straw harmlessness are used to measure the level of green agricultural production. Forest cover rate is used to measure the level of rural nature and ecology. The ammonia emission rate and COD emission rate are used to measure the level of rural ecological management.
(3) Civilized countryside: Intangible cultural heritage, geographical indication, cultural preservation, cultural-tourism combination, cultural creative capacities. This paper refers to the research results of many scholars [10,13,14], the intangible cultural heritage, geographical indication and cultural preservation are mainly used to measure the construction of inherited culture in rural revitalization development. Cultural-tourism combination, cultural creative capacities are used to measure the ability to create and produce culture in the development of rural revitalization.

(4) Affluent living: Per capita grain production, urban-rural income ratio, rural living standards, and rural income level. This aspect of the index is still largely in line with most scholars. Among them, per capita grain production is a key indicator to ensure a prosperous life. Currently, rural areas still rely on food cultivation as the main source of income ([15]). The urban-rural income ratio, rural living standards, and rural income level are used to provide a comprehensive measure of rural affluence.

(5) Effective governance: Rural transportation, rural education, medical conditions, innovation output, technological achievements, agricultural technology market. Among them, rural transportation [16], rural education [17], and medical conditions are used to measure public services [18] and the level of effective rural governance. Innovation output is used to measure the efficiency of the use of resources in the agricultural production process. Technology achievements and agricultural technology market are used to measure the level of science and technology innovation [9,19].

Then, the entropy weight method is used to measure the level of rural revitalization because the entropy value method has the advantage of objective empowerment and can avoid the subjectivity of expert empowerment [6,20]. Considering that the units of measurement of the indicators are not uniform, the indicators are standardized using Eps. (1) before calculation.

$$x_{ij}^{'}=\begin{cases}\left[\dfrac{X_{ij}-min\left(X_{1j},X_{2j}\cdots X_{nj}\right)}{max\left(X_{1j},X_{2j}\cdots X_{nj}\right)-min\left(X_{1j},X_{2j}\cdots X_{nj}\right)}\right]+0.01 & if\ x_{ij}\geq 0\\ \left[\dfrac{max\left(X_{1j},X_{2j}\cdots X_{nj}\right)-X_{ij}}{max\left(X_{1j},X_{2j}\cdots X_{nj}\right)-min\left(X_{1j},X_{2j}\cdots X_{nj}\right)}\right]+0.01 & if\ x_{ij}<0\end{cases} \tag{1}$$

Where $x_{ij}^{'}$ is denoted as x_{ij}, and x_{ij} is the value of the jth indicator for the ith province after treatment, where $i=1, 2, 3$ …….n and $j=1, 2, 3$ …….m. Calculation of the share of the ith province in the jth indicator with Eq. (2).

$$p_{ij}=\frac{x_{ij}}{\sum_{i=1}^{n}x_{ij}},\ (i=1,2.....n, j=1,2.....m) \tag{2}$$

Calculate the entropy of the jth indicator with Eq. (3).

$$e_j=\frac{-1}{ln(n)\sum_{i=1}^{n}P_{ij}\ ln\left(P_{ij}\right)},\ \left(0\leq e_j\leq 1\right) \tag{3}$$

Calculate the coefficient of variation for indicator j with Eq. (4).

$$g_j=1-e_j,\ \left(0\leq g_j\leq 1\right) \tag{4}$$

Calculate the weight of the *jth* indicator in relation to all indicators with Eq. (5).

$$w_j=\frac{g_j}{\sum_{j=1}^{m}g_j} \tag{5}$$

Calculation of the composite score for each province with Eq. (6).

$$s_i=\sum_{j=1}^{m}w_jx_{ij},\ (i=1,2.....n) \tag{6}$$

The larger S_i in the formula indicates the higher level of green agricultural development in province i. The data for the empirical research were based on the China Statistical Yearbook, the China Rural Statistical Yearbook, and statistics on the national economic and social development of provinces and government work reports, etc., which were publicly released by the national statistical departments, and supplemented with data from the studies of scholars in the field.

2.2. Measure of regional disparities: Dagum Gini coefficient

The Dagum Gini coefficient was introduced by Dagum in 1997 and is often used as a measure of intra- (inter-) regional differences. It is superior in dealing with non-equilibrium, data quality and between-group mutation factors [21]. This paper adopts the Dagum Gini coefficient to decompose and measure the level of China's rural revitalization, and while analyzing the gap between provinces as a whole, it probes deeply into the sources of the differences [22–24]. The Gini coefficient of China's level of rural revitalization was calculated according to Eq. (7).

$$G=\sum_{j=1}^{k}\sum_{h=1}^{k}\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}\left|y_{ij}-y_{rh}\right|\Big/2n^2y \tag{7}$$

where, $k=4$ denotes the number of regions divided, n_j denotes the number of provinces and municipalities in the jth region, y_{ij} is the development level of rural revitalization of provinces and municipalities in the jth region, respectively, and $\bar{y}$ is the mean value of the national level of rural revitalization.

Before the Gini coefficient decomposition, it is necessary to rank the regions according to their level of rural revitalization development, such as $\overline{Y_1}\leq\overline{Y_2}\leq\ldots\leq\overline{Y_h}\cdot\leqq\overline{Y_k}$. The Gini coefficient can be decomposed into three parts: intra-regional, inter-regional and hypervariable density, where the intra-regional Gini coefficient G_{jj} and the corresponding contribution G_w can be calculated by Eqs. (8) and (9), respectively, the inter-regional Gini coefficient G_{jh} and the contribution of the net disparity G_{nb} by Eqs. (10) and (11), respectively, and the contribution of the hypervariable density G_t can be calculated by Eq. (12). In the above equation, $p_j=n_j/\ n, s_j=n_j\overline{Y_j}/n\overline{Y}$. D_{jh} denotes the absolute gap in the development level of inter-regional rural revitalization, and $1\text{-}D_h$ is the hypervariable intensity, D_{jh} is calculated by Eq. (13), where $F_h(F_j)$ denotes the cumulative distribution function of the h(j) region, d_{jh} denotes the gap in the development level of inter-regional rural revitalization when $y_{ji}>y_{rh}$, and p_{jh} denotes the hypervariable first-order moment of inter-regional rural revitalization when $y_{ji}<y_{rh}$, which are calculated by Eqs. (14) and (15), respectively.

$$G=\left(1/2\overline{Y_j}\right)\sum_{i=1}^{n_j}\sum_{r=1}^{n_j}\left|y_{ji}-y_{jr}\right|\Big/n_j^2 \tag{8}$$

$$G_w=\sum_{j=1}^{k}G_{jj}p_js_j \tag{9}$$

$$G_{jh} = \sum_{r=1}^{n_j} \sum_{r=1}^{n_h} \left| y_{ji} - y_{jr} \right| / n_j n_h \left(\overline{Y_j} + \overline{Y_h} \right) \tag{10}$$

$$G_{nb} = \sum_{j=2}^{k} \sum_{h=2}^{j-1} G_{jh} \left(p_j s_h + p_h s_j \right) D_{jh} \tag{11}$$

$$G_t = \sum_{j=2}^{k} \sum_{h=1}^{j-1} G_{jh} \left(p_j s_h + p_h s_j \right) D_{jh} \tag{12}$$

$$D_{jh} = \left(d_{jh} - p_{jh} \right) / \left(d_{jh} + p_{jh} \right) \tag{13}$$

$$d_{jh} = \int_0^{\infty} dF_j(y) \int_0^{y} (y - x) dF_h(x) \tag{14}$$

$$p_{jh} = \int_0^{\infty} dF_h(y) \int_0^{y} (y - x) dF_j(x) \tag{15}$$

2.3. Dynamic distribution measure: kernel density function

This paper use Kernel density function to explore the dynamic evolution of the distribution of rural revitalization level in the whole country and regions. Primary reference to current scholarly results [25–27]. $f(c)$ is assumed to be a density function of the level of rural revitalization c in China, then:

$$f(c) = \frac{1}{N\rho} \sum_{i=1}^{N} K\left(\frac{C_i - \overline{c}}{\rho} \right) \tag{16}$$

Table 2
China's rural revitalization level score, 2011–2021.

Province	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	20211	Score	Rank
Shanghai	0.344	0.302	0.338	0.355	0.334	0.408	0.373	0.388	0.355	0.364	0.276	0.349	3
Shandong	0.546	0.544	0.541	0.515	0.549	0.576	0.568	0.563	0.54	0.574	0.497	0.546	1
Zhejiang	0.299	0.298	0.304	0.292	0.297	0.304	0.298	0.314	0.304	0.321	0.293	0.302	22
Hebei	0.302	0.289	0.278	0.278	0.289	0.298	0.283	0.294	0.281	0.313	0.303	0.291	25
Jiangsu	0.297	0.306	0.325	0.291	0.329	0.335	0.336	0.302	0.34	0.341	0.363	0.324	10
Beijing	0.274	0.284	0.292	0.26	0.275	0.292	0.323	0.347	0.375	0.328	0.348	0.308	18
Hainan	0.260	0.305	0.281	0.282	0.281	0.313	0.255	0.295	0.308	0.280	0.295	0.286	29
Tianjing	0.290	0.300	0.308	0.295	0.284	0.318	0.273	0.297	0.297	0.302	0.277	0.294	24
Fujian	0.418	0.433	0.403	0.422	0.424	0.408	0.426	0.396	0.394	0.404	0.407	0.412	2
Guangdong	0.297	0.324	0.310	0.331	0.320	0.291	0.306	0.338	0.298	0.320	0.282	0.310	17
The east	0.332	0.338	0.338	0.332	0.338	0.354	0.344	0.353	0.349	0.354	0.334	0.342	
Hunan	0.331	0.325	0.332	0.324	0.323	0.328	0.327	0.341	0.334	0.355	0.350	0.333	7
Jiangxi	0.279	0.290	0.303	0.287	0.269	0.271	0.276	0.284	0.288	0.283	0.333	0.287	28
Hubei	0.323	0.327	0.323	0.330	0.329	0.336	0.369	0.346	0.350	0.335	0.356	0.339	5
Henan	0.321	0.299	0.321	0.312	0.316	0.332	0.31	0.306	0.306	0.340	0.351	0.319	13
Shanxi	0.271	0.275	0.294	0.310	0.302	0.347	0.343	0.284	0.309	0.303	0.298	0.303	21
Anhui	0.313	0.295	0.328	0.309	0.323	0.315	0.306	0.299	0.322	0.328	0.358	0.317	15
The central	0.306	0.301	0.316	0.312	0.310	0.321	0.321	0.310	0.318	0.324	0.341	0.316	
Sichuan	0.325	0.319	0.319	0.321	0.32	0.336	0.326	0.342	0.31	0.354	0.328	0.327	8
Yunnan	0.285	0.307	0.317	0.319	0.327	0.323	0.33	0.357	0.317	0.341	0.331	0.323	11
Lnner Mongolia	0.286	0.307	0.306	0.328	0.331	0.333	0.353	0.322	0.315	0.350	0.370	0.327	8
Guangxi	0.275	0.283	0.273	0.276	0.280	0.294	0.298	0.292	0.294	0.313	0.315	0.290	26
Qinghai	0.259	0.236	0.272	0.280	0.270	0.244	0.273	0.249	0.291	0.284	0.283	0.267	30
Shanxi	0.318	0.334	0.328	0.323	0.330	0.326	0.340	0.355	0.356	0.381	0.329	0.338	6
Guizhou	0.277	0.266	0.265	0.289	0.282	0.285	0.278	0.331	0.292	0.319	0.312	0.290	26
Chongqing	0.280	0.289	0.311	0.273	0.298	0.293	0.295	0.301	0.309	0.307	0.297	0.295	23
Xinjiang	0.322	0.316	0.335	0.314	0.316	0.307	0.33	0.300	0.306	0.312	0.320	0.316	16
Gansu	0.299	0.266	0.327	0.326	0.337	0.326	0.369	0.332	0.304	0.336	0.327	0.322	12
Ningxia	0.310	0.324	0.281	0.307	0.298	0.31	0.319	0.299	0.282	0.333	0.311	0.306	19
Xizang	0.267	0.265	0.250	0.260	0.296	0.278	0.247	0.284	0.254	0.260	0.262	0.265	31
The west	0.291	0.292	0.298	0.301	0.307	0.304	0.313	0.313	0.302	0.324	0.315	0.305	
Liaoning	0.322	0.298	0.285	0.296	0.325	0.317	0.292	0.318	0.297	0.303	0.323	0.306	19
Heilongjiang	0.359	0.345	0.344	0.326	0.344	0.356	0.353	0.34	0.318	0.344	0.404	0.348	4
Jilin	0.309	0.307	0.297	0.307	0.340	0.312	0.304	0.316	0.332	0.350	0.334	0.318	14
The Northeast	0.330	0.316	0.308	0.309	0.336	0.328	0.316	0.324	0.315	0.332	0.353	0.324	
Nationwide	0.314	0.311	0.315	0.313	0.322	0.326	0.323	0.325	0.321	0.333	0.355		

Note: With reference to the regional division method of the National Bureau of Statistics, China is divided into four major regions: East, Central, West and Northeast. Hong Kong, Macao and Taiwan lack comparability and were not included in the study.

In Eps. (16), N is the number of observations, $K(-)$ is the kernel function, c_i is the number of independent same-step observations, and $\bar{c}$ is the mean value. ρ is the bandwidth, the smaller the bandwidth, the higher the estimation accuracy and the less smooth the curve is. In this paper, we choose the more commonly used Gaussian kernel function to estimate the dynamic evolution of the distribution of China's rural revitalization level, The Kernel function expression is Eps. (17):

$$K(c) = \frac{1}{2\pi} exp\left(-\frac{c^2}{2}\right) \tag{17}$$

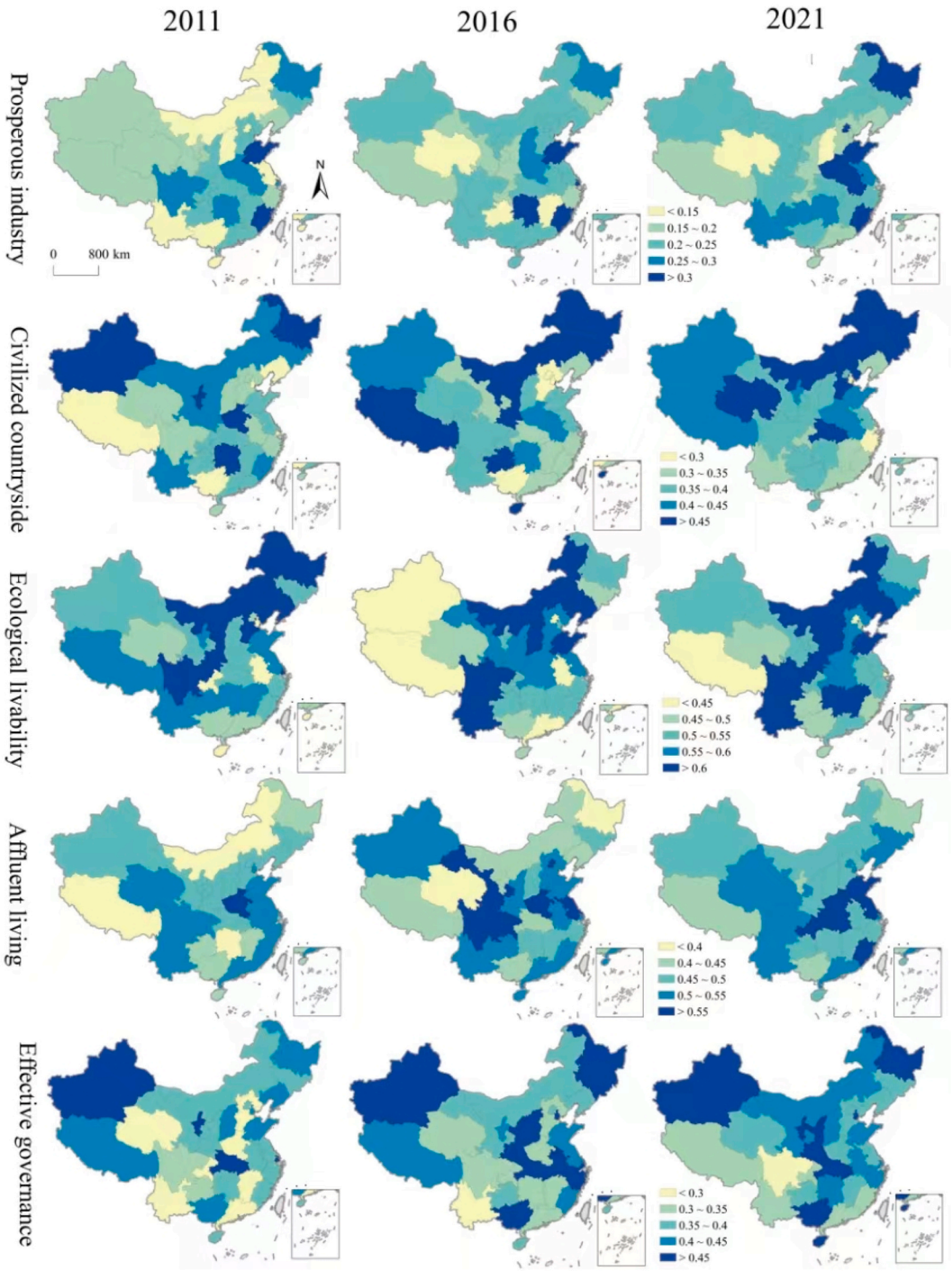

Fig. 1. Rural revitalization sub-dimension visualization map.

3. Results

3.1. The level of rural revitalization

The level of China's rural revitalization from 2011 to 2021 is measured using Eps. (6), and the results are shown in Table 2.

It can be seen from Table 2 that the overall level of rural revitalization development in China has been slowly increasing, with its mean value slowly growing from 0.311 to 0.330, with an average annual growth rate of 1.73 %. At the same time, most provinces also showed a steady upward trend, while a small number of provinces and municipalities showed a downward trend. We can find that Shandong Province, as a typical representative of the upward trend, has a strong agricultural base of its own. Geographical conditions, historical factors, population resources and so on are all very superior, therefore, in promoting the modernization of agriculture, it can quickly accept and adapt, combined with the modernization development, and give full play to its own advantages. A typical commonality among all the provinces on the rise is that they all have their own unique advantages, and in the context of rural revitalization, they have quickly seized the opportunity to give full play to their potential. And Hubei Province as a representative of the fluctuating trend, we can see that part of the identity with a certain foundation, because all aspects are in the middle level, in the process of rural revitalization, can not be well to find their own development positioning, highlighting their own strengths, so that the development of the limitations. Overall, there are fewer provinces with a declining trend, mainly in the northeast, which is more difficult to develop mainly due to its unique climatic conditions. The loss of talents and resources is the main reason for its decline. The average score of the level of rural revitalization is among the top 10 provinces, with four in the east, two in the center, three in the west and one in the northeast, while the average score of the bottom 10 provinces is five in the west, four in the east and one in the center. As can be seen, the relatively high level of development is mainly concentrated in the eastern region. The level of rural revitalization in China is ranked from high to low in the eastern, central, western, and northeastern regions. The possible reason for this is that the eastern region's intensive approach to economic growth and its spatial and geographical location advantages have provided financial, technological, institutional and other support for ecological agriculture and the construction of new rural areas [28], and it has a comparative advantage in terms of the level of rural revitalization. The central and western regions are rich in agricultural and ecological resources, and with the introduction of the "two-type society", the completion of the poverty eradication campaign, and the implementation of ecological projects such as the "Bank of the Two Hills" and the Tianbao Project, the rural revitalization of the central and western regions have also shown greater potential.

At the same time, Arcgis software was used to make a visual map of the level of each province in the country from 2011 to 2021, so as to observe more intuitively its regional differences and dynamic evolution (Fig. 1). We can see that under the sub-dimension of industrial prosperity, the relative advantage of the eastern China is obvious, and the western China is relatively backward. In terms of ecological livability, the eastern China does not have a clear advantage, but rather the central and western China are gradually taking advantage of the northeastern China with the development of time, but there is a clear trend of regression. In terms of rural civilization, it can be seen that there is a gradual improvement in all of them, with the most significant changes in the central and eastern China, and no significant changes in parts of the western China. Some fluctuating changes in terms of livelihood affluence. In terms of effective governance, it can be seen that while some areas in the east and center are relatively good, there is still much room for progress in most areas.

Based on the above results, it is found that the overall level of China's rural revitalization is somewhat similar to the regional distribution of the level of economic development, which is specifically manifested in the gradient distribution of eastern China being better than central China being better than western China being better than northeastern China, while at the same time showing a gradual widening of the inter-regional disparity and the phenomenon of unbalanced development within the region.

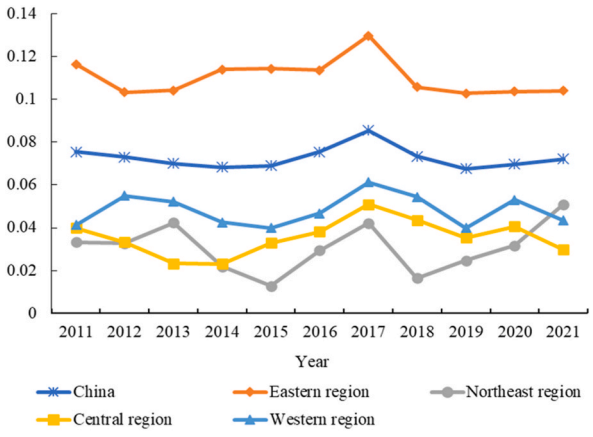

Fig. 2. Regional differences in the level of rural revitalization. Notes: The vertical coordinate represents the Gini coefficient.

3.2. Regional differences in rural revitalization

3.2.1. Overall gaps and trends in the level of rural revitalization

The Gini coefficient for the level of rural revitalization at the national and regional levels was measured using Eqs. (8)–(15) and the corresponding trend changes were plotted (Fig. 2).

The overall gap in the level of China's rural revitalization from 2011 to 2021 shows some volatility (Fig. 2). Rural revitalization trended slowly downward from 2011 to 2014, but the decline was small and remained essentially constant. In the subsequent period, 2015–2018, there was a rapid upward trend and a significant widening of the overall gap. The probable reason is that the Political Bureau of the Central Committee of the Communist Party of China (CPC) considered and adopted the Decision on Winning the Battle Against Poverty in November 2015, which has brought the attention of more societies to rural development [29,30]. The overall gap in the level of rural revitalization shows a great deal of volatility over the period 2018–2021, first declining and then slowly rising after 2020. However, China's vast territory and obvious regional differences have led to a gradual widening of the gap in the level of rural revitalization among provinces since 2015..

3.2.2. Breakdown of gaps in the level of rural revitalization

(1) Gap analysis of the level of rural revitalization within the region. As can be seen in Fig. 2, there is a large regional disparity in the level of rural revitalization between the east and the center of China, both of which showed a downward trend from 2011 to 2012. Regional disparities in the level of rural revitalization in the center, west and north-east are relatively small, with the center showing a declining trend from 2011 to 2014, with an average annual decline of 10.5 per cent. After 2013, the volatility trends in the center and the west remained highly consistent. The western China showed a certain upward trend in 2011–2013, followed by a "W"-shaped trend in 2014–2021, with an average annual growth rate of 17.75 % in the upward phase of 2015–2017.

(2) Gap analysis of the level of rural revitalization among regions. From Fig. 3, it can be seen that in 2011–2021, the inter-regional rural revitalization level gap is widening by varying degrees in all combinations, except for East-Central and East-West, which are narrowing. The largest change was in the central-western of China, where the average annual growth rate was 1.33 percent, reflecting to some extent that the interregional gap in the level of rural revitalization is widening, but the expansion is relatively slow. In terms of the mean value of the Gini coefficient among regions, the Gini coefficient values are generally larger for the three regional groupings of East-Northeast, East-Central and East-West, which is consistent with the findings of the previous analysis. The Gini coefficients of the other three regional combinations are relatively small, i.e., the development of rural revitalization is in a low level of equilibrium among the three regions of central, western and northeastern China.

(3) Analysis of the contribution rate of the gap in the level of rural revitalization between regions. As can be seen from Tables 3 and in 2011–2021, the value of intra-regional disparity contribution and the value of net inter-regional disparity contribution show a decreasing trend, but the decrease is not significant, with the largest decrease being in the value of net inter-regional disparity contribution, which is 32.3 %. There is an upward trend in the value of hypervariable density contributions within the region, with an increase of 36.8 %. In terms of the relative size of the contributions, the basic contribution of the net interregional disparities is basically higher than that of the intraregional disparities. The intra-regional hypervariable density contribution was lower than the intra-regional gap contribution in 2012, 2016, and 2019, and exceeded the intra-regional gap contribution in all other years. This is evidenced by the fact that the contribution of the total interregional gap has remained above 70 per

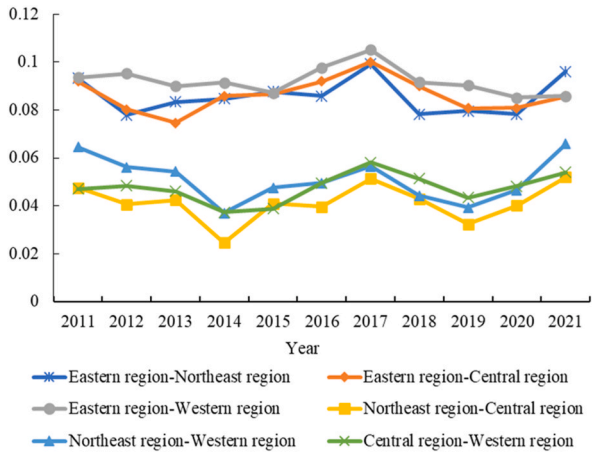

Fig. 3. Decomposition of the gap in rural revitalization between regions
Notes: The vertical coordinate represents the Gini coefficient.

Table 3
Breakdown of the contribution to the gap in rural revitalization.

Year	Overall gap	Regional disparity		Net gap among regions		Intensity of transvariation	
		Value	Rate	Value	Rate	Value	Rate
2011	0.0754	0.0205	27.22	0.0312	41.42	0.0236	31.35
2012	0.0730	0.0209	28.68	0.0339	46.42	0.0182	24.90
2013	0.0701	0.0202	28.88	0.0285	40.66	0.0214	30.46
2014	0.0683	0.0198	28.92	0.0220	32.18	0.0266	38.90
2015	0.0690	0.0196	28.44	0.0234	33.90	0.0260	37.66
2016	0.0754	0.0210	27.90	0.0346	45.87	0.0198	26.23
2017	0.0856	0.0254	29.70	0.0214	25.07	0.0387	45.23
2018	0.0734	0.0215	29.21	0.0292	39.77	0.0228	31.02
2019	0.0675	0.0188	27.80	0.0327	48.38	0.0161	23.82
2020	0.0697	0.0209	30.01	0.0206	29.62	0.0281	40.37
2021	0.0722	0.0188	26.07	0.0211	29.17	0.0323	44.76

cent in 2011–2021. The overall gap in the level of China's rural revitalization comes mainly from differences in the level of development between regions, and the overall gap is slowly narrowing.

4. Discussion

4.1. Analysis of the evolution of distribution dynamics

Using Kernel density estimation to analyze the dynamic evolution of the distribution of the level of rural revitalization across the country and the four regions. Comparisons across time can capture the dynamic features of the distribution of levels of rural revitalization. It also provides an in-depth analysis of the characteristics of spatial and temporal differences in rural revitalization and their influencing factors. This paper use Matlab software and take the Gaussian kernel density function so that $\rho = 0.05$ to plot the three-dimensional map of Kernel density estimation of rural revitalization level of the whole country and the four regions, and the results are shown in Figs. 4 and 5.

Fig. 4 shows that the dynamic evolution of the distribution of the level of rural revitalization in China's 31 provinces, municipalities and autonomous regions from 2011 to 2021 exhibits the following three features: First, the overall distribution of wave heights shows an increasingly steep trend, with a narrowing width and a widening right trailing extension, suggesting that the gap between the levels of rural revitalization in China's provinces is gradually narrowing, but this change is not prominent. Second, the position of the main peak of the overall distribution pattern of the level of rural revitalization keeps moving to the right, from which it is inferred that China's level of rural revitalization keeps rising, but the change in the position of this movement is not obvious. Third, the number of

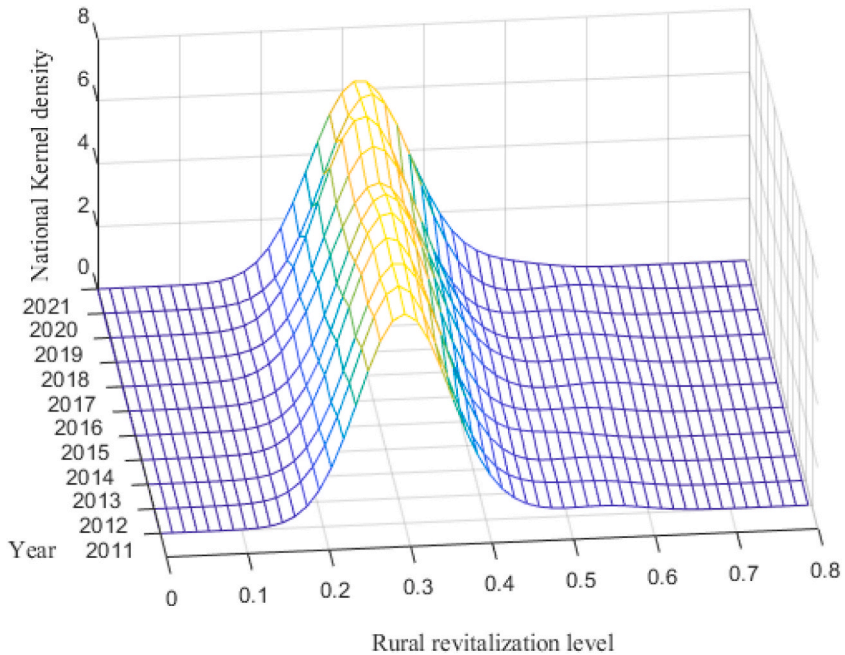

Fig. 4. Dynamic evolution of the distribution of the national level of rural revitalization.

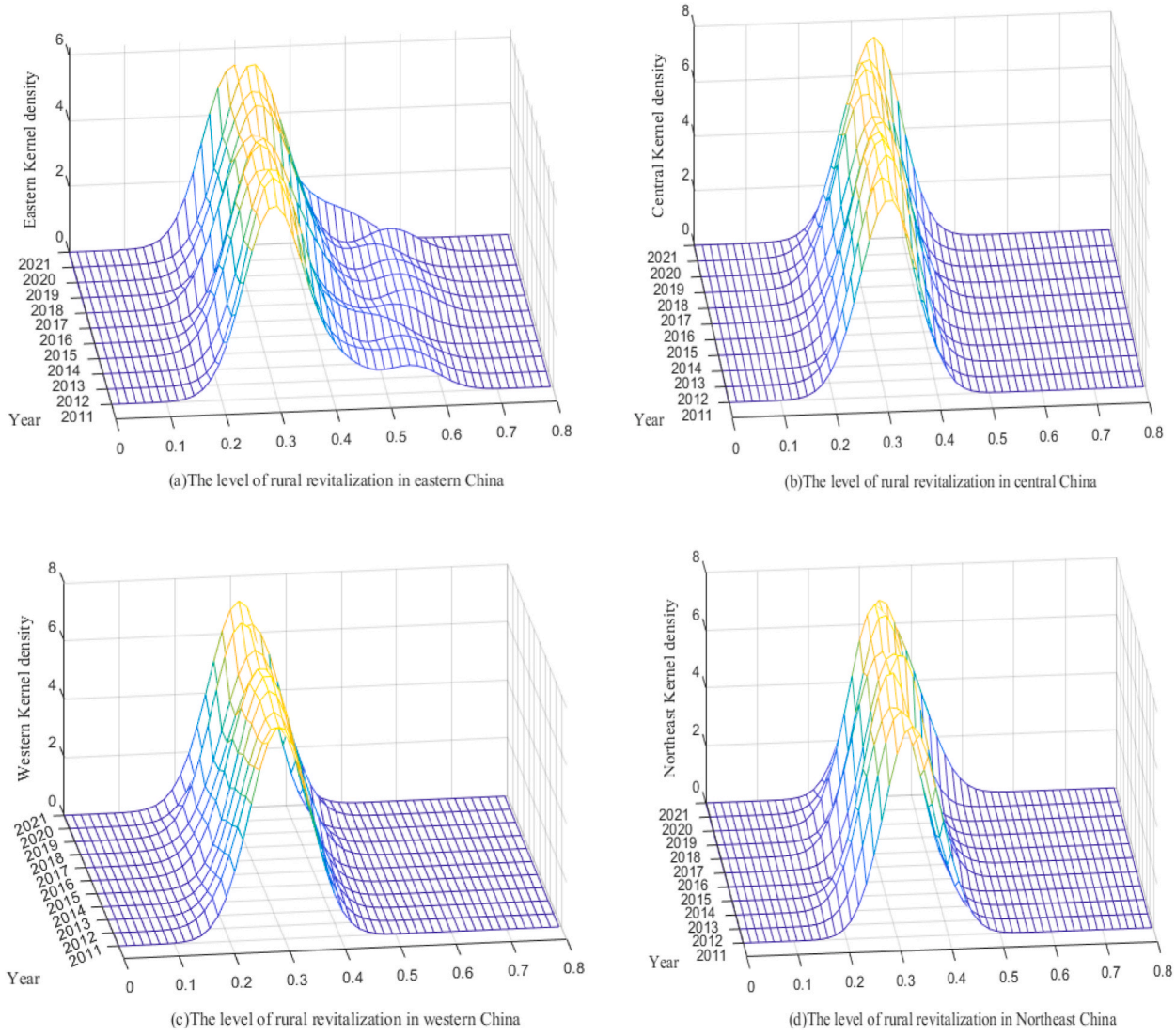

Fig. 5. Dynamic evolution of the distribution of rural revitalization in the four regions. Note: (a) shows the dynamic evolution of the level of rural revitalization in the East. (b) Shows the dynamic evolution of the level of rural revitalization in the Central. (c) Shows the dynamic evolution of the level of rural revitalization in the Western. (d) Shows the dynamic evolution of the level of rural revitalization in the Northeast.

main peaks is always one, indicating that the level of rural revitalization in China has not been polarized or converged. On the whole, here again confirms the previous conclusion that although the level of China's rural revitalization has been increasing year by year, the rate of increase is slow, and there is a certain gap between provinces and the differences are narrowing, and that the level of rural revitalization in China has been decreasing. Happily, there is no multipolarity, meaning that there are gaps but they are not critical.

Based on the previous results of the development level and spatial distribution pattern of rural revitalization, together with Fig. 4, we can analyze the results: Since the implementation of the rural revitalization strategy, all provinces have taken corresponding measures. The investment of resources, policy support and the development of modern technologies such as the digital economy have all contributed to the modernization of the countryside. However, the fact that local governments have a harder time grasping the direction of new rural development and usually follow suit blindly, squeezing the space for development, as well as the siphoning effect of cities on the countryside and the lack of social attention to the countryside, have led to its low-speed development. Provinces with relatively better resource conditions, such as the Shanghai Municipality with advantageous economic resources, the Shandong Province with developed large-scale farming technology and the Zhejiang Province with advanced information network technology, create an obvious gap with the relatively backward Liaoning Province and Tibet. However, because of today's ease of transportation and advanced networks, which have led to the circulation of resources, the gap has narrowed further, albeit more slowly.

Fig. 5(a) shows that the main peak of the distribution curve for the level of rural revitalization in the East shifts to the right and increases in height, indicating an overall increase in the level of rural revitalization in the East. The main peak morphology evolved

from “flat and flat” to “sharp and narrow”. Side peaks appear in 2015–2020, with a tendency for the main peak to be farther away from the side peaks, and a tendency for the width of the side peaks to widen, but with a tendency for the height of the side peaks to decrease, and a tendency for the width of the side peaks to widen. This indicates that there is a tendency for the level of rural revitalization in the east to become polarized, but the absolute differences are tending to narrow. However, there were retractions in 2014, 2018, and 2021, followed by a return to normal, indicating a tendency for differences in levels of rural revitalization to widen in individual years.

Fig. 5(b) shows that the main peak of the distribution curve of the level of rural revitalization in the central part of the countryside shifted with a trend of “right shift to left shift to right shift”, but the overall trend is to move to the right. The main peak is getting steeper and steeper, and the distribution curve always has a right trailing and broadening extension, with only one main peak. It indicates an overall increase in the level of rural revitalization in the Central, with a narrowing trend in absolute differences and no polarization.

Fig. 5(c) shows that the distribution curve of the level of rural revitalization in the west is single-peaked, moving to the right and getting steeper, indicating that there is no polarization of the level of rural revitalization in the west, and that the absolute difference is narrowing and the overall increase.

Fig. 5(d) shows that the distribution curve of the level of rural revitalization in the Northeast has similar characteristics to the distribution curve of the level of rural revitalization in the Middle East. It indicates an overall increase in the level of rural revitalization in the Northeast, with a narrowing trend in absolute differences and no polarization.

Based on this, we can analyze and conclude: The eastern region is developing relatively fast due to the economic, technological and resource advantages of Shandong and Shanghai. This, coupled with the siphoning effect on surrounding provinces, has led to polarization. However, it is also due to the weak foundations of the other provinces in the eastern region, coupled with the mobility of resources, which has led to relatively rapid development and a further gradual narrowing of the absolute gap. The northeastern region is in a state of relatively slow development due to its relatively closed geographical location and similar resource conditions, resulting in a relatively similar level of development. The development of the western region is more similar to that of the northeastern region. However, more favorable natural conditions and policy support have led to a better rate of development than in the Northeast. The central region, on the other hand, is at a relatively rapid level of development due to its relatively good economic, technological and geographical conditions and its proximity and close ties with the eastern region. The provinces in the region have similar resource endowments and therefore are not polarized.

5. Conclusion

In this paper, the entropy weight method is used to measure the level of rural revitalization in China from 2010 to 2021, and a visual map is drawn using Arcgis software. Using Dagum’s Gini coefficient and its decomposition method, we examined the regional differences in China’s rural revitalization level and its sources, and further analyzed the dynamic evolution of its distribution using Kernel’s density function, and the main conclusions we obtained are as follows.

(1) The level of rural revitalization in China is generally low overall, but shows a fluctuating and increasing trend. The average level of rural revitalization grows from 0.314 in 2011 to 0.355 in 2021, a growth rate of 1.18 %, which is generally low and slow overall. Of course there are relatively large differences in subsystem scores between regions. Ecological Livability had the highest mean and growth rates. Civilized countryside is relatively low in both growth rate and average value, which is a shortcoming in the development of rural revitalization. The level of rural revitalization in China is generally low and structurally uneven.
(2) The overall gap in China’s level of rural revitalization comes mainly from inter-regional differences, and the overall gap is slowly narrowing. The Gini coefficient decreases from 0.0754 in 2011 to 0.0722 in 2021, a decrease of 4.24 %. The reduction in overall variance was not significant, with the Gini coefficient remaining consistently below 0.1, and the overall variance was not severe. In terms of regional heterogeneity, regional differences within the East and the Center generally show a downward trend in fluctuations. The Northeast and West show an upward trend in fluctuations, with generally low values for intraregional variances. The decomposition of the overall variance shows that the interregional variance contributes the most, but the overall trend is downward, from 41.42 % to 29.17 %.
(3) China’s level of region-wide rural revitalization is on the rise. Absolute intraregional differences show a gradual reduction, with most regions not experiencing growth polarization. While ensuring a steady increase in the level of rural revitalization, the focus should be not only on working to narrow the gap between regions and provinces, but also on avoiding polarization as much as possible, so as to promote the coordinated development of the level of rural revitalization throughout the country.

Accordingly, the paper makes the following policy recommendations:

First, from an overall perspective, the level of rural revitalization in China is generally low and structurally uneven. Therefore, this paper proposes that policy choices should be based on optimizing existing policies, supplemented by adding new policies as appropriate. In addition, for the aspects of ecological livability and industrial prosperity, it should adjust the original backward industries, especially those that have a greater impact on the environment, and vigorously support the emerging green industries. Increase investment in ecological and environmental protection, carry out large-scale ecological projects, and complete the integration and effective utilization of resources [31]. For the aspects of well-being and effective governance, there should be continued stability in the implementation of existing policies. With regard to the civilization of the countryside, it is also necessary to continue to explore in depth the cultural resources of different regions and ethnic groups.

Secondly, in terms of regional heterogeneity, there is a need to further capitalize on the economic and industrial advantages of the eastern region, thus leading to the comprehensive development of science and technology, culture and ecology. At the same time, the relatively developed provinces and municipalities in the eastern region are allowed to adopt a one-to-one assistance policy for the relatively backward areas within the region, so as to narrow the gap within the region. And make full use of the well-developed Internet technology in the eastern region to promote the development of agricultural economic informatization, so that the agricultural economy can get rid of the constraints of the development ideas of the primary industry, so that the high value-added characteristics of the secondary and tertiary industries can fully contribute to the development of the agricultural economy, so as to find new breakthroughs for the revitalization of the countryside in the eastern region [17]. The central region, which is at the intermediate level, has achieved remarkable development in recent years and has the main option of maintaining and optimizing the policy of rural revitalization, but at the same time the conditions for urban and industrial development to feed the development of rural agriculture are not ripe, which is an important factor limiting the further development of the central region at the present time. It should fully grasp the window of opportunity brought about by the effective convergence of rural revitalization and poverty eradication in the next five years, accelerate the industrial upgrading and optimization of the central region, and guide the transfer of its capital and technology to the countryside, put urban and rural areas in an open, fair, and adjusted development environment, and realize the flow of urban and rural resource elements, the close convergence of industries, and the complementarity of functions, so as to enable the urban and rural modes of production, lifestyles, and ecological environments to move in the integrated direction of harmonious development and promote the development of new rural areas in the central region [32].In the western region, which is relatively backward in terms of level, the development is relatively lagging behind due to the "geographical spell" and resource endowment. However, in recent years, with the further utilization of its ecological resources and the promotion of relevant national major projects, it is being upgraded at a faster rate and has greater development potential. It should not only retain the existing support policies and maintain the existing development achievements, but also add new support policies, rely on the help of the State, but also actively combine their own resources, for their unique ethnic culture, natural scenery, agricultural advantages, etc., out of their own development path. The Northeast, which has been at the end of the scale in recent years, although it has historical factors, the existence of heritage and was ahead of the West before, due to its climatic and geographical factors, it has not been strong enough in recent years and has gradually been overtaken by the West, with ineffective utilization of resources and a massive loss of talents, so we should phase out in time the original policies that do not meet the actual situation. Its backward industries to eliminate and upgrade, strengthen cooperation with local universities, increase the introduction of talent policy support, promote the deep integration of industry, academia and research, looking for new growth points, and promote new vitality in the northeast region.

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Availability of data and materials

All data used in this study are publicly available.

Ethics approval and consent to participate

All our research complies with ethical guidelines, including compliance with the legal requirements of the research country. The authors of this paper have participated in the entire process of this article, including conceptualization, paper ideas, methods, writing, and review.

Consent for publication

As a result of the research, we unanimously agree that this paper can be published in your journal.

CRediT authorship contribution statement

Zhongbo Xiong: Writing – original draft, Software, Formal analysis, Data curation. **Yanzhong Huang:** Writing – review & editing. **Liyan Yang:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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