Pol. J. Environ. Stud. Vol. 31, No. 6 (2022), 5313-5327
DOI: *10.15244/pjoes/150642* ONLINE PUBLICATION DATE: 2022-08-30

Original Research

The Temporal-Spatial Evolution and Driving Mechanism of Rural Green Development in China

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Received: 24 February 2022
Accepted: 2 June 2022

Abstract

Green development is the inherent requirement and important support of comprehensive rural revitalization in China. This study constructs a rural green development index system drawing on the framework of "green growth–green wealth–green welfare" and elaborates the temporal-spatial evolution and driving mechanism of rural green development in 30 provinces in China based on the entropy method, spatial autocorrelation analysis and Geodetector. The results indicate that the rural green development index (RGDI) showed an upward trend from 2004 to 2019, with an average annual growth rate of 7%. Nevertheless, the overall level of rural green development is relatively low. The RGDI presented the spatial differentiation characteristic of high in the eastern region and low in the central and western regions. In particular, the urbanization level, economic scale, industrial structure, and public facility investment are the primary factors driving rural green development. The research proposes relevant policy recommendations from the perspectives of four major regions to improve the rural green development level in China, including green agricultural production, ecological protection, public services and infrastructure investment, and industrial integration.

Keywords: rural development, green development, spatial-temporal evolution, driving mechanism, China

Introduction

Since 2004, when attention turned to China's issue of "agriculture, rural areas and farmers", rural China has experienced the development stages characterized by a series of strategies, including terminating agricultural taxes (2006), new socialist countryside construction (2006), building a beautiful countryside (2008), new-type urbanization (2012) and rural revitalization (2017). Against this background, China's rural areas have achieved remarkable development, and all of the rural poor have been lifted out of absolute poverty. However, the problems of uneven and insufficient development in agricultural economic development, resources and

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environment, and rural society still persist [1]. China's arable land area is less than 10% of that globally, but the amount of chemical fertilizer used is close to 1/3 of the worldwide total, and the fertilizer utilization rate is only 40% [2, 3]. In China's vast rural areas, natural resource shortages, ecosystem imbalances, infrastructure deficits, random discharges of garbage and sewage, inadequacies in housing conditions and amenities like piped water, gas, electric power, sewerage are particularly prominent, and these issues have severely restricted the rural transformation and development [4]. With the increasing impact of resource and environmental bottlenecks on economic and social development, the Chinese government has realized that it must follow the economic and natural laws of regional development, and treat the ecological environment as an important endogenous variable in economic development, consequently elevating green development higher as a national strategy. Starting with the "Eleventh Five-Year Plan", the Central Committee of the Communist Party of China has established requirements for green development ideas, concepts, plans, and indicators. In the most recent "Fourteenth Five-Year Plan", the idea of accelerating green development and promoting the harmonious coexistence of man and nature was once again emphasized. As the most important spatial carrier of natural ecosystems, resources and energy, the rural areas are not only the farmers' home, where they produce and live, but also the production and supply bases for social ecological products and services. Leading rural revitalization with the concept of green development, through rural ecological environmental protection, agricultural green production and rural living environment improvement, is critical to realizing the aspirations of hundreds of millions of farmers for a better life.

Green development inherits from but transcends sustainable development, creating a fundamental break with the traditional extensive economic development model [5]. Green development research originated from the "green economy" proposed by David et al. (1989), who pointed out that economic development should fully consider the capabilities of the natural ecological environment [6]. The "China Human Development Report" published by the UNPD (United Nations Development Programme) proposed that China should choose the path of green development to achieve the unity and coordination between economic development and environmental protection [7]. The UNEP (United Nations Environment Programme) pointed out that the green economy is an important strategy for achieving sustainable development and eradicating long-term poverty [8]. The World Bank believes that green growth is a growth method that uses natural resources efficiently while minimizing environmental pollution and impact and effectively responding to natural disasters [9].

The existing research on green development has focused attention in a range of regions and cities, and the research areas can be classified into the following two categories.

The first is green development evaluation research, which focuses on evaluating green efficiency and comprehensive indices. Many studies have developed complex multiobjective evaluation frameworks and comprehensive indicator systems to analyze the level of green development, such as the green growth framework constructed by the OECD (Organization for Economic Cooperation and Development) [10, 11], and the green development index systems proposed by research institutions and government departments such as the China's National Development and Reform Commission et al. [12] and Beijing Normal University et al. [13]. Some scholars have also proposed the theoretical frameworks and concepts for evaluating green development, including the three-circle model (green growth-green welfare-green wealth) [14], the GG-GE-SD model (green growth-green economy-sustainable development) [15], the five-circle model (economic advancement-resource utilization-ecological environment-social progress-environmental governance) [16], the PREDS model (population-resources-environment-development-satisfaction) [17], the DPSIR model (driving force-pressure-state-impact-response) [18] and the green GDP model [19]. The representative research methods include the Malmquist index [20], Malmquist-Luenberger index [21], DEA [22], entropy method [23], S-type cloud mode [24], and projection pursuit model [25]. In the aspect of rural green development, Xie and Wang (2016) found that the performance of rural green development shows an upward trend overall and obvious region differences in China [26]. Zhou et al. (2019) indicated that the levels of rural green development in Shaanxi Province differed internally in 78 counties [27]. Yu et al. (2020) found that the rural green development efficiency is higher in developed areas than in developing areas and higher in coastal areas than in inland areas [28].

The second research direction investigates spatial heterogeneity and the mechanisms influencing green development. The study of the spatial heterogeneity of green development has a diversified range, covering countries [29-32], typical regions and provinces [33, 34], and typical cities [35, 36]. Research on the influencing factors and driving factors of green development involves economic development, industrial structure, urbanization, financial tools, financial support, environmental regulation, public behavior, etc. The main research methods are spatial autocorrelation analysis [36], IV_2SLS mode [37], LMDI model [38], spatial autoregressive model [39], Geodetector [40], GWR model [41], factor analysis model [17], spatial Durbin model [20], panel threshold regression [21] and Tobit model [22]. In the aspect of rural green development, Yu et al. (2018) indicated that GDP per capita, urbanization, agricultural science and technology level and farmers' investment capacity are important influencing factors of rural green development [42]. Yuan (2019) found that the influencing degree from high to low is rural social development, the bearing capacity of resources and environment, government green support and the degree of agricultural economy greening [43]. Zhang and Liang (2020) found that the industrial structure and living standards had high impacts on rural green development in Henan Province [44].

In general, the research on the development level and efficiency, temporal and spatial evolution, influence and driving factors is relatively mature in the field of green development, but the main study areas concentrate on cities and regions. There are relatively few studies on rural green development, and there is a lack of research on the overall framework, spatial distribution and driving mechanisms of green development in rural areas. Therefore, against the current background in China and the vigorous implementation of the rural revitalization strategy and rural green development, a scientific approach to measuring the level of rural green development in various provinces in China, describing in detail its temporal and spatial differentiation characteristics and spatial correlation characteristics, and comprehensively analyzing its impact and driving mechanisms has important theoretical reference value and practical significance for improving the relevance of government rural green development policies and the effectiveness of their implementation.

The research reported here establishes an assessment system of rural green development based on the framework of "green growth-green welfare-green wealth". The entropy method is adopted to calculate the rural green development index (RGDI) of China's 30 provinces in 2004, 2009, 2014 and 2019. The temporal-spatial distribution characteristics of the RGDI are displayed with ArcGIS 10.7, and the spatial correlation characteristics are described by the spatial autocorrelation model and measured with Geoda. The driving factors of rural green development are determined by Geodetector. On this basis, relevant policy recommendations are proposed to improve the rural green development level in China.

Materials and Methods

Study Area and Data Source

Based on the availability of statistical data, this study selected 30 provinces, cities, and autonomous regions (hereinafter collectively referred to as provinces) as the focus of this research, covering most provinces in China except Hong Kong, Macau, Taiwan, and Tibet. The 30 provinces include Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan, Liaoning, Jilin, Heilongjiang, Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan, Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang. The data are mainly derived from the China Statistical Yearbook, Urban and Rural Construction Statistical Yearbook, China Environmental Statistical Yearbook, and the yearbooks of those 30 studied provinces from 2004 to 2019.

Methods

Entropy Method

The entropy method is adopted to set the weights of the RGDI indicators in this study. First, the initial data are pretreated by the dimensionless range method. The process is as follows:

$$Z_{ij} = \begin{cases} \frac{x_{ij}-\min x_{ij}}{\max x_{ij}-\min x_{ij}} & \text{positive indicators} \\ \frac{\max x_{ij}-x_{ij}}{\max x_{ij}-\min x_{ij}} & \text{negative indicators} \end{cases} \tag{1}$$

where *i* represents the province, $1 \le i \le n$; *j* represents the measurement indicator, $1 \le j \le m$; x_{ij} represents the raw value of the indicator, and Z_{ij} represents the standardized value of the indicator.

Second, the proportion Y_{ij} of indicator *j* for province *i* is calculated with the following formula:

$$Y_{ij} = \frac{Z_{ij}}{\sum_{i=1}^{n} Z_{ij}} \tag{2}$$

Third, the information entropy E_j of indicator *j* is calculated with the following formula:

$$E_j = \frac{1}{\ln(n)} \sum_{i=1}^{n} Y_{ij} \times \ln(Y_{ij}) \tag{3}$$

Fourth, the information entropy redundancy D_j is calculated with the following formula:

$$D_j = 1 - E_j \tag{4}$$

Fifth, the weight of the indicators is calculated. The indicators weights are positively correlated with their contribution to the measurement results, that is, the higher the weight is, the greater that indicator's contribution to the measurement results. The calculation formula of weight W_j is:

$$W_j = \frac{D_j}{\sum_{j=1}^{m} D_j} \tag{5}$$

Finally, the RGDI_i is calculated, and the calculation formula is:

$$\text{RGDI}_i = \sum_{j=1}^{m} W_j \times X_{ij} \tag{6}$$

Spatial Autocorrelation Analysis

This study uses the global Moran's *I* and local Moran's I_i to measure the overall spatial correlation characteristics and the local spatial aggregation state of RGDI. The calculation formulas are:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i-\bar{x})(x_j-\bar{x})}{s^2\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \quad (7)$$

$$I_i = \frac{(x_i-\bar{x})}{s^2}\sum_{j=1}^{n} w_{ij}\left(x_j-\bar{x}\right) \quad (8)$$

where $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$, $s^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2$, x_i and x_j represent the observation values of regions *i* and *j*, *n* is the number of regions, and w_{ij} is the spatial weight matrix.

The global Moran's *I* ranges from [-1, 1]. The closer its value is to 1 (-1), the stronger the positive (negative) correlation among the different regions, and a value close to 0 means that there is no spatial autocorrelation among them. The local Moran's I_i measures the spatial distribution pattern of high-high and low-low associations (I_i >0), and high-low and low-high associations (I_i <0).

Geodetector

This study adopts Geodetector [45] to determine the extent to which the driving factor X explains the spatial differentiation of RGDI, measured by the q value. The formula is as follows:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h\sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST} \quad (9)$$

where *h* is the stratification of RGDI or X. N_h and *N* are the sample numbers of the stratification and the whole area. σ_h^2 and σ^2 are the variance in RGDI of the layer *h* and the whole area. *SSW* is the sum of intralayer variance, and *SST* is the total variance of the whole area.

The value range of *q* is [0, 1], where the larger the value is, the stronger the explanatory power of the driving factor X in RGDI, with a lower value having weaker explanatory power. Geodetector is good at analyzing the type quantities. Therefore, the natural breakpoint method in ARCGIS 10.7 is used to discretize and stratify the values of the driving factor X, from low value to high value, respectively, 1, 2, 3, 4, 5.

Index System Construction

Since green development is a highly complex system comprising economic, social and ecological environments, multifaceted factors should be considered when evaluating its level. This study mainly draws on the "three-circle model" [14] to build the RGDI system and emphasizes the overall optimization and coordination of the three subsystems of green growth, green wealth, and green welfare.

The three subsystems are interconnected and coordinated, wherein green growth is the core, green wealth is the foundation, and green welfare is the goal. Green growth reflects economic efficiency and resource utilization efficiency in the production process and mainly includes two factors: agricultural efficiency and ecological economy. It is the guarantor of green welfare and green wealth. Green wealth represents the capacity of the ecological environment and the resource carrying of the region and consists of resource abundance and environmental governance. It refers to the sum of various natural factors on which biological survival and development depend and is the carrier of green welfare and the foundation of green growth. Green welfare reveals the impact on human well-being on the process of regional development, including residential life, infrastructure and public services. It is the safety and security welfare of human life and a vital target of green development.

Based on the statistical frequency analysis of relevant indicators proposed by existing studies [5, 39-42] and after ensuring their scientific basis, comprehensiveness, integrity, and availability, the RGDI evaluation system was constructed, covering 3 subsystems, 7 factors and 26 indicators. Based on formulas (1)~(5), the weights of the indicators were calculated, as shown in Table 1.

Results and Discussion

Temporal-Spatial Evolution of RGDI

Temporal-Spatial Variation in RGDI

The RGDI was obtained using the formula (6) and is shown in Table 2. Overall, the RGDI of all provinces in China showed a steady upward trend from 2004 to 2019. In terms of the national average, it rose from 0.0907 in 2004 to 0.2499 in 2019, with an average annual growth rate of 7%. Nevertheless, the RGDI of all provinces is lower than 0.5, which indicates that the rural green development in China is still at a low level and has great potential for improvement.

During the study period, the RGDI of Beijing, Shanghai, Hainan, Jiangsu, Zhejiang, Fujian, Inner Mongolia and Qinghai were consistently in the top ten; these are primarily coastal provinces in the southeast except Inner Mongolia and Qinghai. In contrast, the bottom ten are mainly central and western provinces, such as Anhui, Guizhou, Henan, Gansu, Xinjiang and Shanxi. The ranking range of most provinces is relatively stable, while a few provinces fluctuate greatly. For instance, from 2004 to 2019, the northeastern provinces of Liaoning and Jilin dropped from 10th to 23rd and 13th to 28th, respectively. Meanwhile, the western provinces of Ningxia and Yunnan rose from 24th to 15th and 20th to 10th, respectively.

There are also large, obvious differences among the provinces. In 2004, the disparity between Beijing (0.2936), the highest ranked, and Guizhou (0.0492), the lowest ranked, represents a multiple of 5.97. In 2019, the disparity between the highest ranked Beijing (0.4916) and the lowest ranked Shanxi (0.1827) was a multiple of 2.69. Although the interprovincial differences are gradually decreasing, the gap is still glaring.

To intuitively observe the spatial evolution of rural green development, this study divided the RGDI of 30 provinces into six levels. As diagrammatically represented in Fig. 1, the rural green development presented the spatial differentiation characteristic of high in the east and low in the center and west during the study period.

Spatial Association of RGDI

To continue to study the spatial agglomeration situation and correlation characteristics of rural green development in China from 2004 to 2019, the spatial autocorrelation model was used to calculate the global Moran's *I* and draw the Moran scatter diagram using Geoda, as exhibited in Fig. 2. The horizontal axis represents standardized RGDI, and the vertical axis represents the RGDI of each province by weighting spatial weighted matrixes, which is the spatial lag level of RGDI of each province.

Table 1. Evaluation Index System of RGDI.

Subsystem	Factor	Indicator (Unit)	Calculation or description of the indicators	Indicator direction	Indicator weight
Green growth	Agricultural efficiency	Per capita output value of agriculture, forestry, animal husbandry and fishery (yuan/person)	Gross output value of agriculture, forestry, animal husbandry and fishery/rural population	+	0.0270
		Proportion of effective irrigation area in cultivated land area (%)	Effective irrigated area/cultivated area	+	0.0250
		Grain production per unit of arable land (t/hm^2)	Grain output/cultivated area	+	0.0197
	Ecological economy	Energy consumption per unit output value (t/ten thousand yuan)	Agriculture, forestry, animal husbandry and fishery coal consumption/gross output value of agriculture, forestry, animal husbandry and fishery	-	0.0021
		Amount of fertilizer used per unit output value (t/ten thousand yuan)	Agricultural fertilizer application amount/gross output value of agriculture, forestry, animal husbandry and fishery	-	0.0059
		Pesticide usage per unit output value (t/ten thousand yuan)	Pesticide usage/gross output value of agriculture, forestry, animal husbandry and fishery	-	0.0065
		Amount of agricultural plastic film used per unit output value (t/ten thousand yuan)	Agricultural film usage/gross output value of agriculture, forestry, animal husbandry and fishery	-	0.0030
Green wealth	Resource abundance	Per capita cultivated area (hm^2/person)	Arable land/rural population	+	0.0314
		Water resources per capita (m^3/person)	Total water resources/rural population	+	0.0555
		Forest coverage rate (%)	Forest area/land area	+	0.0223
		Proportion of wetland area in land area (%)	Wetland area/land area	+	0.0616
		Per capita afforestation area (hm^2/person)	Afforestation area/rural population	+	0.2404
	Environmental governance	Soil erosion control area per capita (hm^2/person)	Soil erosion control area/rural population	+	0.0449
		Per capita biogas project gas production (m^3/person)	Rural biogas project output/rural population	+	0.0441
		Per capita solar water heater area (m^2/person)	Rural solar water heater area/rural population	+	0.0663
		Prevalence of sanitary latrines (%)	Total number of sanitary toilet households/total rural households	+	0.0105

Table 1. Continued.

Subsystem	Factor	Indicator (Unit)	Calculation or description of the indicators	Indicator direction	Indicator weight
Green welfare	Residential life	Per capita housing area (m^2/person)	Total area of rural housing/rural population	+	0.0206
		Per capita disposable income (yuan/person)	Per capita disposable income of rural residents	+	0.0350
		Per capita consumer expenditure (yuan/person)	Per capita consumption expenditure of rural residents	+	0.0351
		Engel coefficient (%)	Per capita consumption expenditure on food, tobacco and alcohol of rural residents/per capita consumption expenditure of rural residents	-	0.0094
	Infrastructure	Water supply penetration rate (%)	Water supply coverage in villages	+	0.0121
		Electricity consumption per capita (kwh/person)	Rural electricity consumption/rural population	+	0.1323
		Mobile phones ownership (unit/household)	Mobile phones owned by rural residents/rural households	+	0.0198
	Public service	Health technicians per thousand population (person)	Rural health technicians/rural population	+	0.0200
		Student-teacher ratio of ordinary primary and secondary school (%)	Students in rural primary and secondary schools/full-time teachers in rural primary and secondary schools	-	0.0070
		Old-age insurance participation rate (%)	Rural residents insured by basic old-age insurance/rural population	+	0.0424

Table 2. Calculation results of RGDI.

Ranking	2004		2009		2014		2019	
	Province	Value	Province	Value	Province	Value	Province	Value
1	Beijing	0.2936	Beijing	0.3997	Beijing	0.3953	Beijing	0.4916
2	Shanghai	0.1559	Shanghai	0.2300	Shanghai	0.3769	Shanghai	0.4086
3	Hainan	0.1436	Hainan	0.1994	Hainan	0.2739	Hainan	0.3219
4	Zhejiang	0.1290	Zhejiang	0.1774	Jiangsu	0.2469	Jiangsu	0.3056
5	Fujian	0.1018	Tianjin	0.1573	Zhejiang	0.2458	Zhejiang	0.2926
6	Jiangsu	0.0979	Jiangsu	0.1510	Fujian	0.2268	Fujian	0.2733
7	Heilongjiang	0.0972	Fujian	0.1350	Inner Mongolia	0.2195	Inner Mongolia	0.2686
8	Inner Mongolia	0.0939	Inner Mongolia	0.1349	Hubei	0.2043	Qinghai	0.2570
9	Qinghai	0.0915	Qinghai	0.1342	Shandong	0.2031	Hubei	0.2468
10	Liaoning	0.0912	Heilongjiang	0.1336	Qinghai	0.2000	Yunnan	0.2458
11	Tianjin	0.0906	Shandong	0.1324	Tianjin	0.1990	Heilongjiang	0.2439
12	Guangdong	0.0897	Liaoning	0.1279	Heilongjiang	0.1967	Jiangxi	0.2419
13	Jilin	0.0889	Jiangxi	0.1208	Jiangxi	0.1945	Shandong	0.2403
14	Jiangxi	0.0869	Guangdong	0.1193	Hunan	0.1916	Hunan	0.2380
15	Shandong	0.0848	Jilin	0.1163	Liaoning	0.1899	Ningxia	0.2336
16	Hubei	0.0828	Hubei	0.1152	Guangxi	0.1887	Sichuan	0.2297
17	Hunan	0.0792	Hunan	0.1147	Guangdong	0.1865	Chongqing	0.2270
18	Hebei	0.0765	Hebei	0.1129	Yunnan	0.1847	Guangdong	0.2269

Table 2. Continued.

Ranking	2004		2009		2014		2019	
	Province	Value	Province	Value	Province	Value	Province	Value
19	Guangxi	0.0733	Yunnan	0.1111	Sichuan	0.1829	Tianjin	0.2263
20	Yunnan	0.0725	Shaanxi	0.1100	Chongqing	0.1828	Guangxi	0.2237
21	Chongqing	0.0672	Sichuan	0.1097	Shaanxi	0.1786	Anhui	0.2195
22	Shaanxi	0.0672	Guangxi	0.1080	Hebei	0.1771	Shaanxi	0.2182
23	Sichuan	0.0649	Shanxi	0.1057	Anhui	0.1716	Liaoning	0.2136
24	Ningxia	0.0645	Chongqing	0.1039	Henan	0.1685	Hebei	0.2113
25	Xinjiang	0.0619	Ningxia	0.1017	Jilin	0.1684	Guizhou	0.2102
26	Shanxi	0.0598	Henan	0.0989	Ningxia	0.1674	Henan	0.2085
27	Anhui	0.0575	Anhui	0.0897	Shanxi	0.1624	Gansu	0.2040
28	Henan	0.0573	Gansu	0.0857	Guizhou	0.1545	Jilin	0.1990
29	Gansu	0.0510	Xinjiang	0.0831	Gansu	0.1531	Xinjiang	0.1865
30	Guizhou	0.0492	Guizhou	0.0795	Xinjiang	0.1522	Shanxi	0.1827
Mean value	0.0907		0.1333		0.2048		0.2499	

According to the calculation results, the global Moran's I index rose from 0.114 in 2004 to 0.152 in 2009 and 0.151 in 2014 and then fell to 0.071 in 2019, showing a fluctuating trend. The value is greater than 0 during the study period, indicating a spatial agglomeration phenomenon. In other words, areas with a higher RGDI tend to be adjacent to other higher RGDI areas, while areas with a lower RGDI also tend to be adjacent.

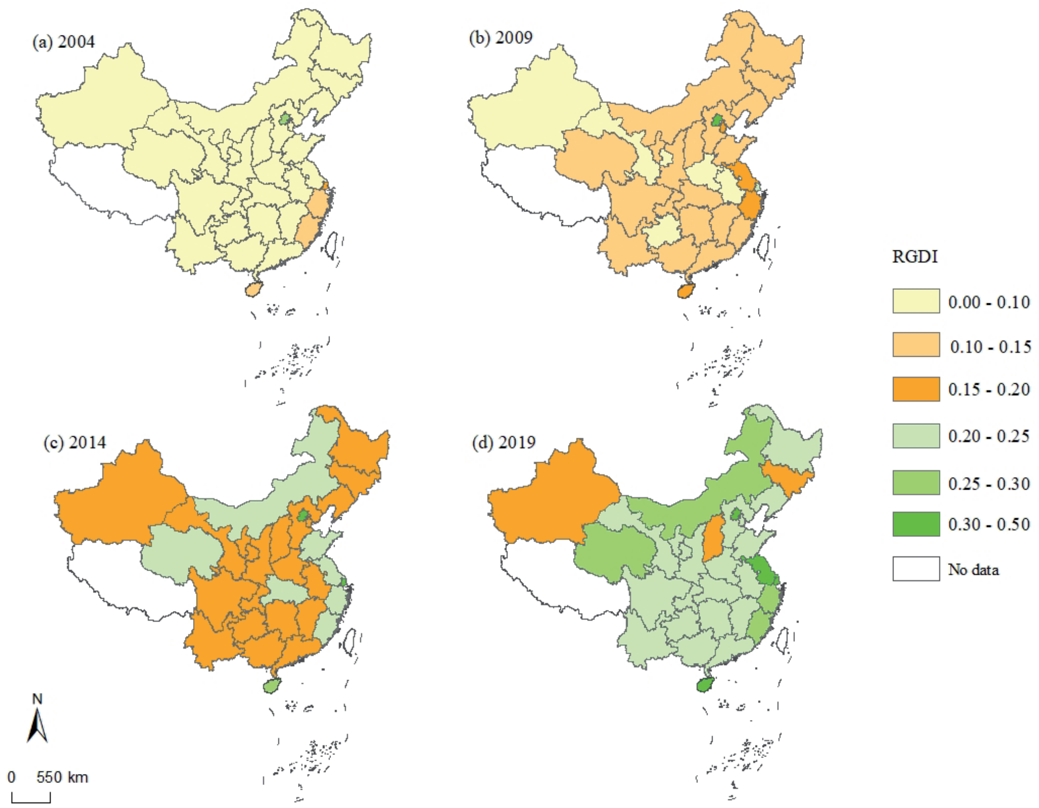

Fig. 1. Temporal-spatial distribution of RGDI.

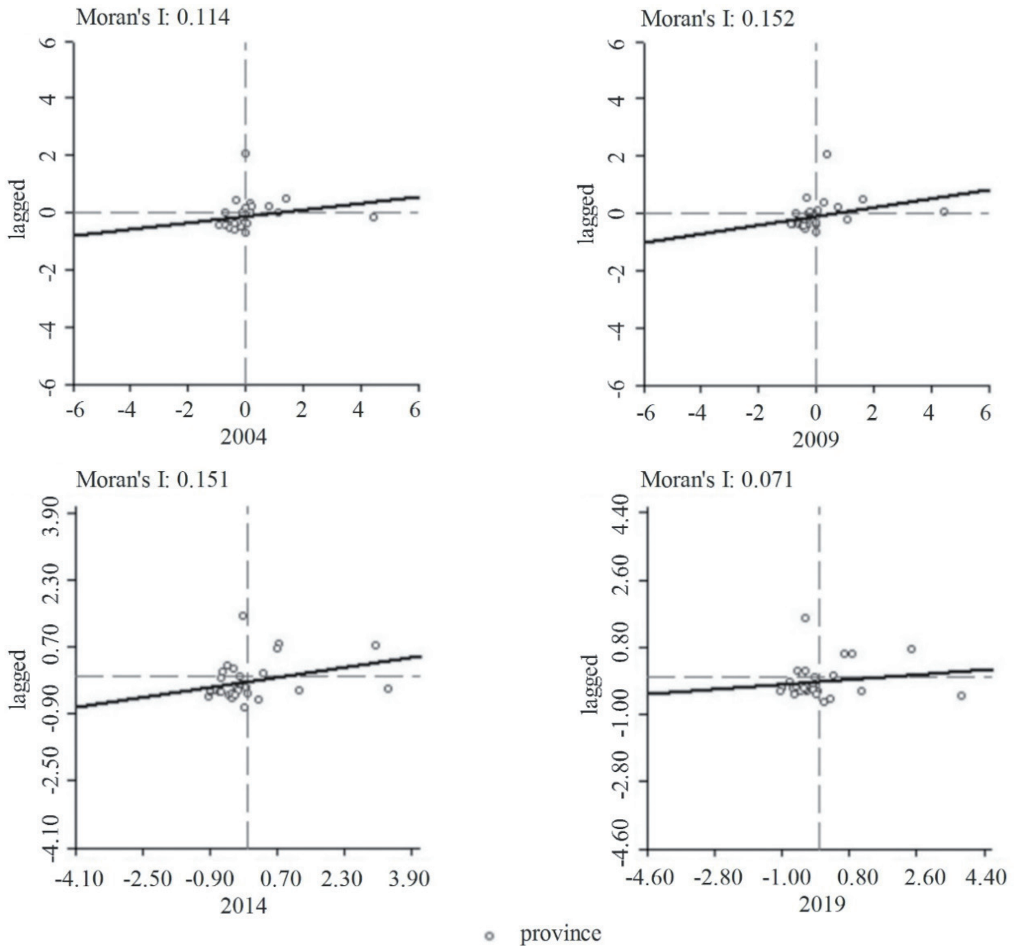

Fig. 2. Moran scatter diagram of RGDI.

The first to fourth quadrants of the Moran scatter diagram can be sequentially divided into four patterns of spatial association: HH (high-high association) areas, LH (low-high association) areas, LL (low-low association) areas, and HL (high-low association) areas. Table 3 lists the spatial association patterns of the 30 provinces in 2004, 2009, 2014, and 2019. In general, the RGDI presents strong spatial dependence, and only 16.67%~20% of the provinces present spatial heterogeneity; these are located in the second quadrant (LH) and fourth quadrant (HL).

The results demonstrate that most provinces are LL areas; these are mainly distributed in the western, central and northeastern regions. The RGDI of these provinces and their neighbors is relatively low, and the spatial association reveals low-level regional agglomeration. In contrast, the HH areas are chiefly concentrated in the eastern coastal region, such as Shanghai, Jiangsu, Zhejiang and Fujian. These provinces have high RGDI values and are surrounded by other provinces with high RGDI values. Hebei and Guangdong have always been LH areas, which implies that their RGDI is relatively low, but they are surrounded by provinces with high RGDI. Inner Mongolia has always been an HL area, which indicates that its RGDI is higher than that of its neighbors.

From the perspective of temporal-spatial transitions in RGDI, the spatial association patterns of most provinces remained the same over the study period. As seen in Table 3, only individual provinces showed transitional characteristics from 2004 to 2019, including Heilongjiang (HH-HL-LL), Jilin (LH-LL), Tianjin (HH-LH), Hainan (HH-HL), Beijing (HL-HH-HL), Shandong (LL-HL-LL), Qinghai (HL-LL-HL) and Anhui (LL-LH). The transitioning provinces accounted for approximately 26.67% of the observed provinces, reflecting the relative stability of the spatial association of RGDI.

Temporal-Spatial Evolution of Green Growth, Green Wealth, and Green Welfare

Temporal-Spatial Variation in Green Growth, Green Wealth, and Green Welfare

From 2004 to 2019, the average annual growth rates of green growth, green wealth, and green welfare were 5%, 4%, and 11%, respectively. Clearly, green welfare has seen the most rapid increase, and this increase is inseparable from the long-term implementation of rural development policies since 2004 in China, such as new socialist countryside construction, building

Table 3. Dynamic change in Moran's I scatter diagram of RDGI.

Year	HH	LH	LL	HL
2004	Tianjin, Shanghai, Jiangsu, Zhejiang, Fujian, Heilongjiang, Hainan	Hebei, Guangdong, Jilin	Chongqing, Shanxi, Sichuan, Ningxia, Xinjiang, Guangxi, Gansu, Guizhou, Yunnan, Shanxi, Henan, Hubei, Hunan, Jiangxi, Liaoning, Anhui, Shandong	Inner Mongolia, Qinghai, Beijing
2009	Tianjin, Shanghai, Jiangsu, Zhejiang, Fujian, Beijing	Hebei, Guangdong	Chongqing, Shanxi, Sichuan, Ningxia, Xinjiang, Guangxi, Gansu, Guizhou, Yunnan, Shanxi, Henan, Hubei, Hunan, Jiangxi, Liaoning, Anhui, Jilin	Inner Mongolia, Qinghai, Shandong, Heilongjiang, Hainan
2014	Shanghai, Jiangsu, Zhejiang, Fujian	Hebei, Guangdong, Anhui, Tianjin	Chongqing, Shanxi, Sichuan, Ningxia, Xinjiang, Guangxi, Gansu, Guizhou, Yunnan, Shanxi, Henan, Hubei, Hunan, Jiangxi, Liaoning, Jilin, Heilongjiang, Shandong, Qinghai	Inner Mongolia, Beijing, Hainan
2019	Shanghai, Jiangsu, Zhejiang, Fujian	Hebei, Guangdong, Anhui, Tianjin	Chongqing, Shanxi, Sichuan, Ningxia, Xinjiang, Guangxi, Gansu, Guizhou, Yunnan, Shanxi, Henan, Hubei, Hunan, Jiangxi, Liaoning, Jilin, Heilongjiang, Shandong	Inner Mongolia, Qinghai, Beijing, Hainan

a beautiful countryside, targeted poverty alleviation, and rural revitalization. The government's investment in rural infrastructure and public services has continued to increase, and the living standards of rural residents have also improved dramatically.

Furthermore, the three subsystems of RGDI reveal different temporal-spatial variation characteristics, as exhibited in Fig. 3. In terms of green growth, Jiangsu, Fujian, Hainan, Heilongjiang, and Liaoning take the leading positions, while Gansu, Shanxi, Guizhou, Ningxia and Yunnan lag behind, mainly reflecting the characteristics of high in the east and low in the west. According to the RGDI results in Table 1, Heilongjiang and Liaoning are at the middle and lower levels. However, these two provinces are rich in agricultural resources and have higher agricultural production efficiency. Thus, their green growth remains at a relatively high level.

With regard to green wealth, Beijing, Shanghai, Hainan, Inner Mongolia and Qinghai are ranked at the top, while Shanxi, Henan, Hebei, Anhui and Xinjiang are at the bottom, which reflects the characteristics of low in the central region and high in the east and west. According to the RGDI results in Table 1, Qinghai and Inner Mongolia have consistently been in the top ten, mainly owing to the high level of green wealth. These two provinces have relatively favorable natural environmental conditions and lower populations, accompanied by strong resource and environmental carrying capacity. In contrast, the per capita resources of Shanxi, Hebei, Henan and Anhui are comparatively low, which results in a low level of green wealth.

In terms of green welfare, Beijing, Shanghai, Zhejiang, Jiangsu and Tianjin are at a high level, while Gansu, Guizhou, Ningxia, Guangxi and Xinjiang are at a low rank. The spatial difference in green welfare is relatively small. Except for some eastern provinces, there is no large gap among the other regions, indicating that rural construction and revitalization have achieved full coverage, and the settlement and living standards of rural residents have been comprehensively improved.

Regional Difference in Green Growth, Green Wealth, and Green Welfare

To examine the four major economic regions in China, the 30 sample provinces can be divided into the northeast region (Liaoning, Jilin, Heilongjiang), eastern region (Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan), central region (Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan), and western region (Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang). To further identify the spatial distribution of rural green development, the average values of green growth, green wealth, and green welfare of the four major regions from 2004 to 2019 are calculated, as shown in Fig. 4.

The eastern region is clearly in the leading position of the three subsystems. Except for the slightly lower green growth than the northeastern region in 2014 and 2019, the eastern region held the top ranking in green growth, green wealth, and green welfare during the study period. This is attributed to the sound economic foundation, natural resources and social development of the eastern region. Specifically, the southeastern coastal areas, which have made great strides in developing green agriculture and constructing an ecologically sound and livable countryside, have advantages in location, capital, technology and systems.

With regard to the northeast region, the green growth ranking is constantly improving; in contrast, green wealth and green welfare continue to fall in the rankings. Because it is reliant on abundant agricultural resources, the northeast region has continued to invest in green agricultural development and has achieved much progress. However, with gradually increasing

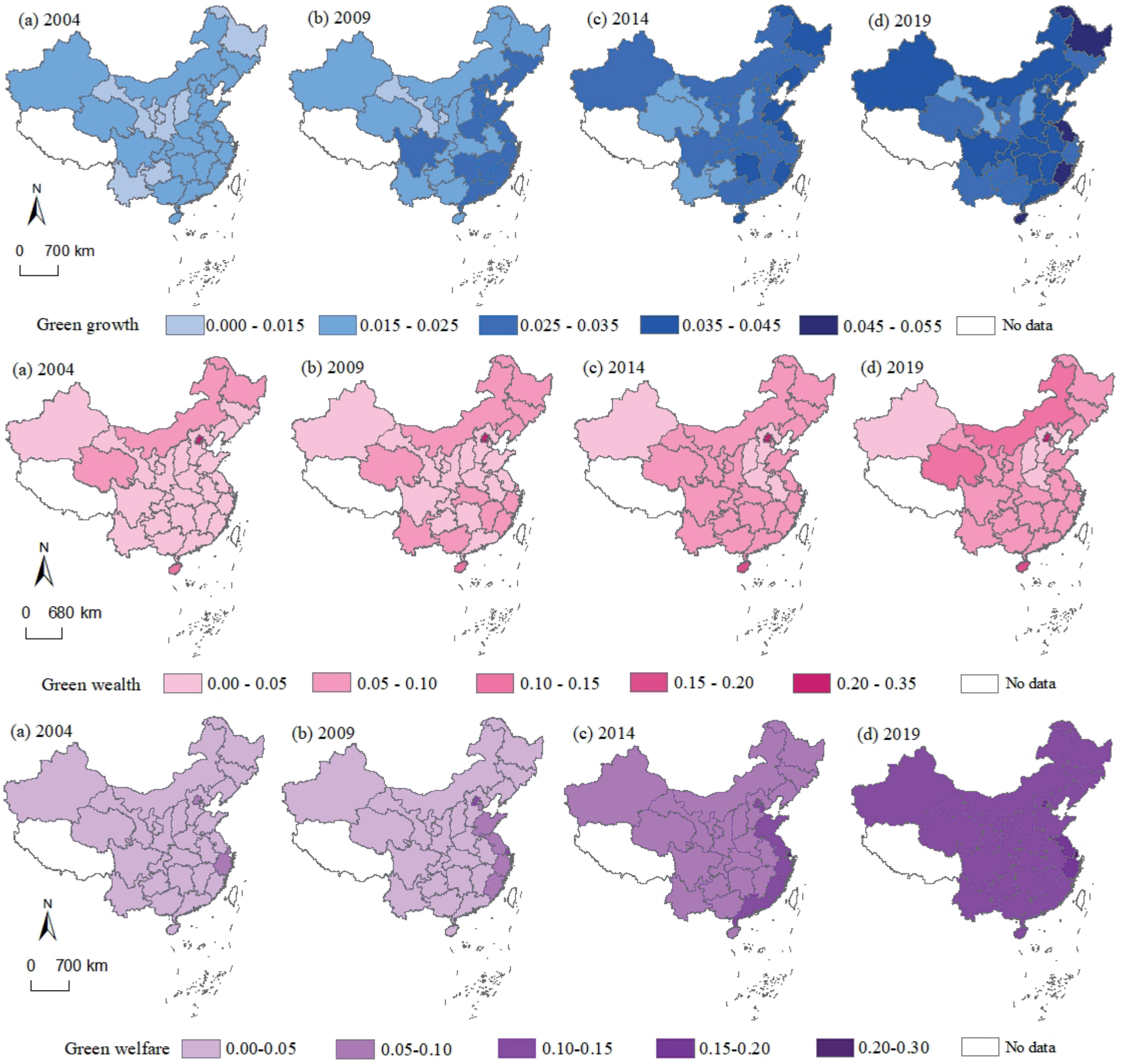

Fig. 3. Temporal-spatial distribution of green growth, green wealth, and green welfare.

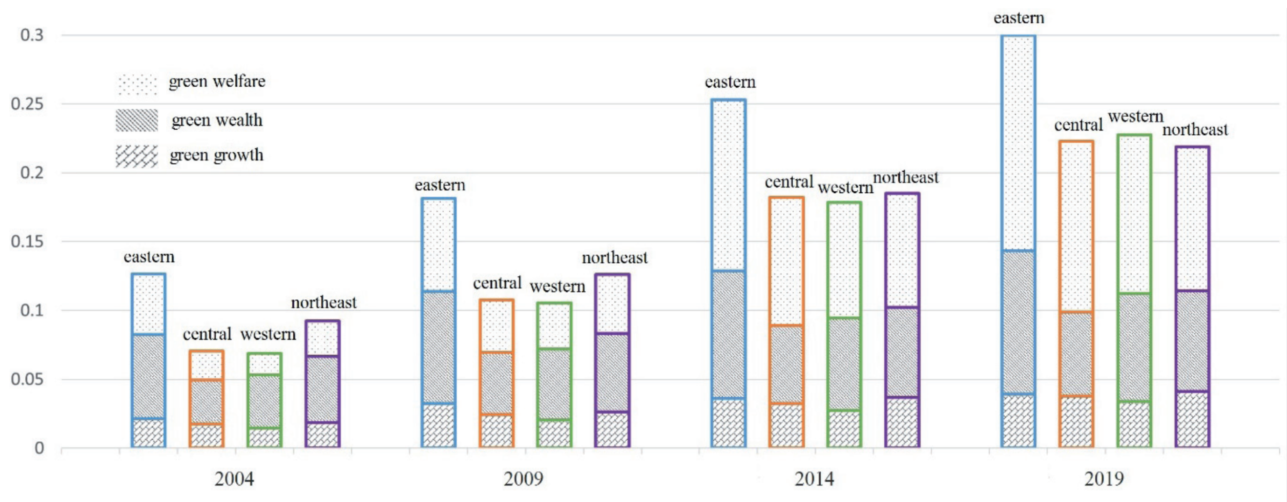

Fig. 4. Green growth, green wealth, and green welfare in the eastern, northeast, central, and western regions.

prominence of economic depression, environmental contamination, rural hollowing out and other problems, as well as the limited investment in rural environmental governance and infrastructure construction, the northeast region lost its edge in green wealth and green welfare, eventually dropping to the lowest level of RGDI in 2019.

The western region remains the lowest in green growth during the study period. The economic and social development of the western region has been in a unadvanced position due to its geographical disadvantages, inadequate transportation, talent flight and capital shortage. Low agricultural production efficiency and heavy agricultural nonpoint source pollution have hindered the green agricultural development. However, per capita resources and environmental conditions are relatively abundant in the western region, which has driven some advances in green wealth.

The central region consistently ranks last in green wealth during the study period. The central region does not have a superior overall resource and environmental conditions, and its population and economic scale are relatively limited, which reveals a contradiction between the insufficient carrying capacity of its resources and environment and the high demand for economic development. The per capita resource occupation and the effect of environmental governance in the central region are relatively weak, which resulted in it having the lowest level of green wealth. Nevertheless, the level of green welfare in the central region has been steadily increasing, consequently, it holds a solid third ranking in RGDI from 2004 to 2019.

In addition, as shown in Fig. 4, the regional disparities between the central, western and northeastern regions gradually decreased. From 2004 to 2014, the RGDI ranking is eastern region > northeast region > central region > western region; however, it shifts to eastern region > western region > central region > northeast region in 2019, which reveals the progressive trend in the western region and the regressive trend in the northeast. The 2014 RGDI of the eastern region, which had the highest position, was 1.8357 times that of the western region, which had the lowest position. By 2019, the gap between the highest eastern region and the lowest northeast region had reduced to 1.3702 times. Although the discrepancy narrows, there still exists a large gap among the three regions (central, western and northeastern) and the eastern region.

Driving Factors of Rural Green Development

Driver Detection Model

The temporal-spatial evolution of RGDI and the three subsystems are affected by diversified factors including the internal conditions and external environment, which are characterized by regionalization, integration, dynamics and complexity. Based on the relevant factors proposed by existing studies [42-44], this study selected 9 driving factors in the fields of urban-rural differences, economic scale and industrial structure, government investment and construction investment, as shown in Table 4.

The factor detector of Geodetector was used to detect the influence of the above driving factors on RGDI and the three subsystems, and the q value was calculated as shown in Table 5. The results reveal that the pivotal factors driving RGDI are the urbanization rate, economic scale, primary industry development, tertiary industry development and public facilities investment. For the three subsystems, the income difference between urban and rural residents and the economic scale have a strong influence on green growth, the tertiary industry development and public facilities investment are the key drivers of green wealth, and the greatest number of factors drive green welfare,

Table 4. Driving factor detection index system.

Detection field	Detection factor	Indicator (unit)
Urban-rural differences	Urbanization rate (X1)	Urban population/total population (%)
	Income difference between urban and rural residents (X2)	Per capita disposable income of urban residents/per capita disposable income of rural residents (%)
	Consumption difference between urban and rural residents (X3)	Per capita consumption expenditure of urban residents/per capita consumption expenditure of rural residents (%)
Economic scale and industrial structure	Economic scale (X4)	Per capita GDP (yuan)
	Primary industry development (X5)	GDP of primary industry/total GDP (%)
	Tertiary Industry development (X6)	GDP of tertiary industry/total GDP (%)
Government investment	Fiscal expenditure for agriculture (X7)	Local fiscal expenditure on agriculture, forestry and water affairs/local fiscal general budget expenditure (%)
Construction investment	Public facility investment (X8)	Rural municipal public facility investment/rural population (yuan/person)
	Housing investment (X9)	Rural housing investment/rural population (yuan/person)

Table 5. Driver detection results.

Driving factors		X1	X2	X3	X4	X5	X6	X7	X8	X9
RGDI	2004	0.7325	0.3274	0.2985	0.5087	0.5442-	0.7898	0.4716	0.7985	0.2414
	2009	0.5884	0.3628	0.4209	0.5817	0.4851	0.6946	0.4080	0.7658	0.2440
	2014	0.5795	0.1300	0.1130	0.5809	0.5469	0.8464	0.2251	0.7382	0.4493
	2019	0.4971	0.0380	0.1051	0.7768	0.5150	0.7474	0.1313	0.3453	0.1407
Green growth	2004	0.2463	0.4840	0.5304	0.4735	0.1307	0.1784	0.5094	0.2655	0.0655
	2009	0.5730	0.4684	0.1205	0.5934	0.3000	0.1591	0.3956	0.2108	0.1716
	2014	0.2503	0.6544	0.2028	0.5328	0.0655	0.3357	0.1297	0.0494	0.0843
	2019	0.2227	0.3465	0.2120	0.3640	0.2842	0.1452	0.1253	0.3162	0.0674
Green wealth	2004	0.4757	0.1155	0.0935	0.3172	0.3814	0.7871	0.2552	0.7803	0.1964
	2009	0.2990	0.1547	0.2238	0.2889	0.3124	0.5299	0.1965	0.5287	0.1327
	2014	0.2782	0.0167	0.0702	0.2685	0.3378	0.5100	0.2061	0.7300	0.6837
	2019	0.2716	0.0459	0.2269	0.4571	0.3392	0.4995	0.0407	0.1678	0.1386
Green welfare	2004	0.7639	0.5805	0.6843	0.8342	0.7042	0.5155	0.7084	0.7323	0.3274
	2009	0.6540	0.4491	0.6581	0.7144	0.6368	0.6350	0.5482	0.7627	0.2705
	2014	0.5707	0.1696	0.1501	0.5886	0.5851	0.6605	0.4119	0.6663	0.2054
	2019	0.5136	0.1626	0.0978	0.7357	0.5615	0.5540	0.4558	0.4119	0.0476

including urbanization rate, economic scale, primary industry development, tertiary industry development, fiscal expenditure for agriculture and public facilities investment.

Driving Mechanism of Rural Green Development

According to the results of the driver detection, the driving mechanism of rural green development can be described as the following four aspects.

First, the urbanization level is a critical driving force behind rural green development. As seen in Table 4, the urbanization rate has a significant impact on RGDI, especially on the green welfare subsystem. China is in a stage of rapid urbanization, with the urbanization rate rising from 41.76% in 2004 to 62.71% in 2019. Reasonable urbanization cannot be achieved without the participation of farmers and rural resources, and thus it simultaneously promotes the development of rural industry and improvements in living standards, which contributes to rural green development. With the continuous advancement of regional urbanization, the concept of ecological civilization and the demand for green development have gradually expanded, which will also have a certain impact on the improvement of the environmental governance system, thereby enhancing the level of green development. It is worth noting that the q value of the urbanization rate showed a downward trend from 2004 to 2019, indicating that its influence on rural green development is decreasing gradually.

Second, economic scale and industrial structure are important foundations for rural green development. The growth in economic scale has a significant impact on RGDI, especially on the subsystems of green growth and green welfare. Rural green development is deeply affected by the development of primary and tertiary industries, whereby tertiary industry has a stronger driving effect than primary industry according to the q value results. Moreover, the tertiary industry has a vital impact on green wealth and green welfare, while primary industry only significantly affects green welfare. The rationalization and advancement of the industrial structure plays an important role in improving the level of social welfare development and reducing the coercive effect on resources and the environment. Tertiary industries such as rural tourism and e-commerce promote resource utilization efficiency and rural ecological landscapes, which enhances the green degree of rural development.

Third, public facility investment is a strong guarantee of rural green development. Public facility investment has a significant impact on RGDI, green wealth and green welfare. The public facilities in rural areas mainly include roads and bridges, water supply and drainage, gas, heating, landscaping, environmental sanitation, sewage treatment and garbage treatment, and they reflect the environmental governance capacity and infrastructure construction level. Complete public facilities can obviously optimize the rural living environment, and constitute an important guarantee for realizing rural residents' expectations for a better life. Public facility investment maintains a high q value from 2004 to 2014, which indicates that it vigorously stimulates the rural green development during this decade. However, the q value declined significantly in 2019, which reflects the increasing independence of rural green development in the new era from public service facility investment, followed by the continuous improvement of the coverage and depth of public facilities in rural areas.

Finally, fiscal expenditure for agriculture, the difference in income and consumption between urban and rural residents and rural housing investment are secondary driving forces of rural green development. Fiscal expenditure for agriculture has relatively little effect on RGDI and has a certain impact on green welfare, with a gradually declining influence. The income difference between urban and rural residents has a smaller impact on RGDI but influences the green growth to some extent. Both the consumption difference between urban and rural residents and rural housing investment have no obvious effect on RGDI and the three subsystems.

Conclusions

This study constructed a rural green development index system drawing on the framework of "green growth-green wealth-green welfare" and elaborated the temporal-spatial evolution and driving mechanism of rural green development in 30 provinces in China based on the entropy method, spatial autocorrelation analysis and Geodetector. The main conclusions are outlined below.

(1) The rural green development presented the spatial differentiation characteristic of high in the eastern region and low in the central and western regions from 2004 to 2019 in China. More than 60% of the ten leading provinces were located in the eastern region, while the lowest ten comprised of 30% central provinces and over 40% western provinces. Most of the central and western provinces revealed the low-level regional agglomeration. Although individual provinces had higher levels of rural green development in the central and western regions, such as Inner Mongolia, Qinghai and Hubei, the trickle-down effect had not yet been formed. For the three subsystems, the western region scored worst in green growth, indicating the inadequate development of agricultural efficiency and ecological economy. The central region scored worst in green wealth, showing the weakness in resource abundance and environmental governance. Both the western and northeastern regions were the lowest in green welfare, therefore, these two regions should be strengthened in residential life, infrastructure and public services.

(2) The overall level of rural green development is relatively low in China, and there is still plenty of room for development. The RGDI showed an upward trend from 2004 to 2019, with an average annual growth rate of 7%, mainly driving by the factors of urbanization level, economic scale, industrial structure, and public facility investment. In order to further promote rural green development in China, efforts must be made in agricultural productivity improvement, tertiary industry development, environmental governance, and infrastructure construction.

According to the research conclusions, it is imperative to promote green rural development in light of local conditions and narrow the gap among different regions. Therefore, the following suggestions are offered.

(1) On the basis of rapid economic development, the eastern region should lead the transformation of green agricultural production and operation modes through the research, development and promotion of green production technologies to vigorously develop new forms of green agriculture. It is essential to advocate and encourage rural residents to adopt green and low-carbon lifestyles. Furthermore, the eastern region should form regional leading advantages in the process of development, and present a good diffusion effect. Eventually, effective radiation will be realized in the central and western regions.

(2) The central region should focus on accelerating urbanization and take advantage of the momentum from rapid social and economic development, thereby strengthening and guiding social investment in rural ecological protection. It is imperative to improve the rural infrastructure and public service facilities and establish a multitype and diversified collection, transportation and treatment system for rural household garbage and sewage that suits rural conditions. Moreover, the energy supply and consumption structure are in urgent need of upgrading in rural areas through clean energy development and utilization in light of local conditions, green and energy-efficient building construction, and energy-efficient agricultural technology adoption.

(3) As an economically less developed area, the western region should establish an excellent green agricultural production system to reduce land, air and water pollution from agricultural production and operation activities and improve the agricultural production efficiency. Meanwhile, it is necessary to further improve the mechanism for ensuring investment in education, health, culture and infrastructure such as water, electricity, roads and communications in rural areas. Furthermore, provinces with higher levels of green development, such as Inner Mongolia, Qinghai and Yunnan, should play a leading role and demonstrate the positive effects.

(4) The northeastern region should rationally adjust the structure of agriculture, forestry, animal husbandry and fisheries to adapt measures to local conditions and should select to develop green final agricultural products with comparative advantages. It is essential to stimulate the vitality of rural tertiary industry, and further realize

the organic integration of primary and tertiary industry. A more reasonable industrial structure will promote the rapid development of the rural economy and improve the living standards of rural residents. In addition, building a number of green development demonstration sites can be a highly effective way to lead to regional development and narrow the gap with other regions.

Due to the richness and complexity of green development theory, the limitations of statistical data, and differences in statistical caliber, it is challenging to establish a comprehensive index to reflect the rural green development. In the future, we will continue to revise the rural green development indicator system established here and further carry out research on monitoring and early warning systems.

Acknowledgments

This research was funded by the MOE (Ministry of Education in China) Project of Humanities and Social Sciences (No. 18YJC630187).

Conflict of Interest

The authors declare no conflict of interest.

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