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ARTICLE

Spatial evolution of green development at provincial level in China

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ABSTRACT

Based on the Green Development Indicator System issued by the Chinese government, this study conducted an in-depth evaluation of provincial green development in China, from 2013 to 2016. The findings of the study showed that: (1) significant regional differences existed across provinces in China regarding green development. (2) In terms of changing trends, the overall level of green development exhibited an upward trend during the years covered by our study, with a faster rising rate of development in eastern and central regions of China than in western ones. (3) In terms of spatial correlation, the spatial autocorrelation of China's green development was evident. However, the spatial agglomeration of provincial green development gradually waned during the period in 2013–2016. (4) When it comes to drivers of spatial autocorrelation, the comparatively upward trend in the environmental field served as the main factor that drove green development from agglomeration to balance. (5) In terms of convergence, the tendency showed that less developed regions were about to catch up with leading regions in China in green development, especially as regards the dimensions of ecological protection and resource utilization.

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Green development; spatial correlation; spatial convergence

1. Introduction

Green development is the basic direction of China's economic and social development during the 13th Five Year Plan (FYP) period and beyond. Since the 18th National Congress of the Communist Party of China (CPC), the country has introduced a series of intensive policy measures and made noticeable achievements in the related fields of green development. Reports of the 19th National Congress of the CPC has placed the requirement for ecological civilization and green development in a more prominent position, thus ushering in a new era of green development. The present situation, spatial pattern, and evolution characteristics of green development are obviously issues worthy of further attention and study, which is required to further improve the level and optimize the spatial pattern of green development in China.

Up to now, studies on green development have mainly focused on green national economic accounting, multi-index measurement methods, and creating a composite green development index (Zheng et al. 2013). The predominant methodology applied in existing studies has been to build a comprehensive evaluation system for green development, of which, the most influential ones include the Green Development Index, developed by Beijing Normal University (Li et al. 2014) and the Resource and Environmental Performance Index, developed by Chinese Academy of Sciences (Sustainable Development Strategy Study Group, Chinese Academy of Sciences 2006). Many scholars (Su et al. 2013; Zeng and Bi 2014; Wu and Huang 2017) also assessed the level of China's green development by constructing a comprehensive evaluation system. However, these index systems put more emphasis on the economic aspect other than the ecology and environment.

In order to strengthen the monitoring and evaluation of green development, the National Development and Reform Commission (NDRC), National Bureau of Statistics (NBS), Ministry of Environmental Protection (MEP), and CPC Organization Department jointly published the *Green Development Index System (GDIS)* (in December, 2016) in order to make the annual evaluation of local green development. On this basis, NBS conducted preliminary calculations (in December, 2017) of the provincial green development that occurred in 2016 (National Bureau of Statistics 2017). However, given the static feature, those results cannot indicate the progress and effectiveness of green development in

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the dynamic view. Therefore, on the base of GDIS, this study intends to analyze the changes and spatial evolution characteristics of provincial green development which have taken place since the 18th CPC National Congress, which is expected to provide a basis for the objective evaluation of regional green development and a reference for policy-making in the future practice of green development.

2. Methodology and data

2.1. Green development measurement

The GDIS contains 55 objective indicators of six categories, including resource utilization, environmental governance, environmental quality, ecological protection, growth quality, and green life. The system also clarifies the weight of each indicator, as well as the weighting method (National Development and Reform Commission 2016). Compared with existing index systems, GDIS holds the salient features as follows: 1) GDIS provides a more comprehensive investigation of green development. The indicators embody the key aspects of green development and basically cover the major tasks of green development as specified in the 13th FYP. 2) GDIS also offers a more prominent examination of ecological and environmental protection. The indicators in GDIS give a weight of 16.5% to ecological protection and also various ecological elements, such as forests, wetlands, grasslands and oceans, are taken into consideration. 3) GDIS also provides defined targets for cap and intensity control of energy resources, pollutant emissions and environmental quality, on the contrast most of the existing studies focused on intensity indicators while paying too little attention to the aggregate indicators. 4) GDIS gives combined consideration on process indicators and outcome indicators, such as environmental governance and environmental quality, as well as resource utilization and resource output.

Due to the limitation of accessibility of some relevant indicators in GDIS, we need to make some adjustments. The post-adjustment system is still comprised of six parts. Specifically, resource utilization covers energy, water, and land use. Environmental governance covers pollutants, hazardous waste, domestic solid waste, and sewage treatment. Environmental quality consists of fine particulate matter ($PM_{2.5}$), surface water, drinking water, nearshore waters, and cultivated land. Ecological protection comprises forests, grasslands, wetlands, protected areas, and soil conservation. Growth quality refers to growth rate, income levels, industrial structure, and innovation investment. Green life includes the indicators of domestic water, domestic electricity, transportation, green space, and environmental sanitation.

The adjustment adheres to the principles as follows: 1) Ensuring the originality and authority of the index system. In maximum compliance with the original index system, similar alternative indicators are used to substitute the original ones, while ensuring the weight of the primary indicators remains unchanged. 2) As regards the public availability of various indicators, those indicators would be removed when the public statistics are unavailable or data are only available from few provinces and cities. 3) All restrictive indicators are reserved. In order to minimize the impact of indicator substitution on the evaluation, all the restrictive indicators with the largest weights are retained in the study hereby. In addition, in order to reflect the variation extent and the development trends in different regions, the exercises of converting as many as possible absolute indicators to relative indicators and aggregate indicators to growth indicators are taken in the study.

As shown in Table 1, the refined provincial green development index system of our research encompasses 45 indicators, of which 42 are original, converted, or alternative indicators. That figure represents 76% of the original total number and 93% of the general weight. Therefore, the refined system is basically consistent with the original system.

The data mainly comes from various volumes of *China Statistical Yearbook, China Energy Statistical Yearbook, China Industrial Statistical Yearbook, China Environmental Yearbook, China Health Yearbook*, as well as provincial statistical yearbooks, provincial environmental status bulletins, and provincial soil and water conservation bulletins, etc. According to the indicators and their weights, the green development index can be calculated via the following method:

$$Z = \sum_{i=1}^{N} W_i Y_i \quad (1)$$

wherein Z is the green development index which reflects the overall level of green development, Y represents dimensionless indicators, W is the weight of indicators, and N is the number of indicators.

For the indicator weight, we keep the weights of all primary indicators unchanged. When an indicator is excluded, the weight of the removed indicator will be allocated to other indicators in the same primary category, according to the ratio of existing indicators. In addition, the marine indicators only apply to provinces with coastlines. For inland provinces, the weight of these indicators would be allocated to other indicators.

Table 1. Provincial green development index system.

Primary Indicators	No.	Secondary Indicators	Unit	Weight	Property
Resource Utilization (weight = 29.3%)	1	Growth rate of total energy consumption	%	2.17	Reverse
	2	Reduced energy consumption per unit of GDP	%	3.26	Forward
	3	Reduced carbon dioxide (CO_2) emissions per unit of GDP	%	3.26	Forward
	4	Percentage of nonfossil fuels used in primary energy consumption	%	3.26	Forward
	5	Growth rate of total water consumption	%	2.17	Reverse
	6	Reduced water consumption per 10,000 Chinese Yuan (CNY) of GDP	%	3.26	Forward
	7	Water consumption reduction rate per unit of industrial added value	%	2.17	Forward
	8	Farmland growth rate	%	3.26	Forward
	9	Percentage of newly-added construction land in total construction land	%	3.26	Reverse
	10	Reduction rate of construction land use per unit of GDP	%	2.17	Forward
	11	Comprehensive utilization rate of general industrial solid waste	%	1.09	Forward
Environmental Governance (weight = 16.5%)	12	Reduced total chemical oxygen demand (COD) emissions	%	2.75	Forward
	13	Reduced total ammonia nitrogen emissions	%	2.75	Forward
	14	Reduced total sulfur dioxide (SO_2) emissions	%	2.75	Forward
	15	Reduced total nitrogen dioxide (NO_2) emissions	%	2.75	Forward
	16	Disposal and utilization rate of hazardous waste	%	0.92	Forward
	17	Pollution-free disposal rate of domestic solid waste	%	1.83	Forward
	18	Centralized sewage treatment rate	%	1.83	Forward
	19	Percentage of environmental pollution control investment in GDP	%	0.92	Forward
Environmental Quality (weight = 19.3%)	20	Percentage of days with good air quality in cities at the prefecture level or above	%	3.22	Forward
	21	Decline in the $PM_{2.5}$ concentration in cities at the prefecture level or above	%	3.22	Forward
	22	Percentage of Class III or better surface water bodies	%	3.22	Forward
	23	Percentage of surface water bodies inferior to Class V	%	3.22	Reverse
	24	Percentage of Class III or better urban centralized drinking water sources in cities at the prefecture level or above	%	2.14	Forward
	25	Percentage of nearshore waters with good water quality (Class I and II)	%	2.14	Forward
	26	Fertilizer use per unit of farmland area	kg/ha	1.08	Reverse
	27	Pesticide use per unit of farmland area	kg/ha	1.08	Reverse
Ecological Protection (weight = 16.5%)	28	Forest coverage	%	3.44	Forward
	29	Forest stock volume per unit of land area	100 million m^3/km^2	3.44	Forward
	30	Percentage of grasslands in administrative areas	ha	2.13	Forward
	31	Percentage of wetlands in administrative areas	%	2.13	Forward
	32	Percentage of terrestrial nature reserves in administrative areas	%	1.00	Forward
	33	Additional area of soil erosion control	ha	1.00	Forward
Growth Quality (weight = 9.2%)	34	Per capita GDP growth rate	%	1.83	Forward
	35	Per capita disposable income of residents	CNY/person	1.83	Forward
	36	Percentage of tertiary industry in GDP	%	1.83	Forward
	37	Percentage of six major energy-intensive industries in the total industrial output value	%	1.83	Reverse
	38	Percentage of research & development expenditure in GDP	%	1.83	Forward
Green Life (weight = 9.2%)	39	Per capita daily water consumption	m^3/person	1.31	Reverse
	40	Per capita daily electricity consumption	kWh/person	1.31	Reverse
	41	Green transportation (passenger traffic volume of public transportation per 10,000 urban population)	10,000 person-times /10,000 persons	1.31	Forward
	42	Green coverage in built-up urban areas	%	1.31	Forward
	43	Penetration rate of tap water in rural areas	%	1.31	Forward
	44	Penetration rate of hygienic toilets in rural areas	%	1.31	Forward
	45	Per capita green space	ha/10,000 persons	1.31	Forward

Notes: 1) Resource utilization: Due to data unavailability, three original indicators cannot be calculated (i.e. crop irrigation water use factor, resource output rate, and crop straw utilization rate). Therefore, these monitoring indicators (rather than restrictive indicators) are removed, and the corresponding weights are equally allocated to other indicators according to proportion. Some absolute indicators pertaining to energy, water and farmland are converted to relative indicators. For example, the total energy consumption is replaced by the growth rate of total energy consumption, and the percentage of newly-added construction land in total construction land is replaced by the scale of newly-added construction land.

2) Environmental quality: The water quality compliance rate of functional areas of important rivers and lakes cannot be differentiated at the provincial level. Therefore, this indicator is deleted. The safe utilization rate of contaminated farmland is also excluded, due to data unavailability, and the corresponding weight is equally allocated to other indicators, according to proportion.

3) Ecological protection: Due to data unavailability, some of the original indicators cannot be effectively calculated, including the retention rate of natural shorelines, marine protected area, remediation rate of decertified land, and additional area of mine recovery and management. Nevertheless, the indicators used in this study basically reflect the degree of ecosystem protection. Of these indicators, the forest stock volume per unit of land area is an absolute indicator, as opposed to the original relative indicator of forest stock volume. The percentage of grasslands in administrative areas, percentage of wetlands in administrative areas, and percentage of terrestrial nature reserves in administrative areas are used to replace the comprehensive vegetation cover of grasslands, wetland protection rate, and area of terrestrial nature reserves, respectively.

4) Growth quality: The percentage of six major energy-intensive industries in the total industrial output value is used as an alternative indicator to the percentage of strategic emerging industries in GDP, since there is no uniform definition of emerging strategic industries.

5) Green life: The original indicators include the reduction rate of the per capita energy consumption of public institutions, market share of green products, growth rate of new energy vehicle ownership, green transportation (passenger traffic volume of public transportation per 10,000 urban population), percentage of green buildings in new urban buildings, coverage in built-up urban areas, penetration rate of tap water in rural areas, and penetration rate of hygienic toilets in rural areas. Out of the data availability considerations, many indicators are replaced by supplementary indicators that can reflect the overall status of green life, such as per capita daily water consumption, and per capita electricity consumption.

2.2. Spatial autocorrelation analysis

Spatial autocorrelation analysis is a method that is commonly used to study the evolution of the spatio-temporal patterns of some attributes in a certain region (Cheng et al. 2015). Spatial autocorrelation, including global spatial autocorrelation and local spatial autocorrelation, is usually measured by means of the Moran Index.

1) Global spatial autocorrelation describes whether the agglomeration of a specific attribute exists in the overall space. The calculation formula is written as follows:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}|y_i - \bar{y}||y_j - \bar{y}|}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\sum_{i=1}^{n}(y_j - \bar{y})^2} \tag{2}$$

wherein I is the Global Moran's I; n is the number of regions; y_i and y_j denote the respective attribute value of the geographical units i and j, and $\bar{y}$ denotes the average attribute value of each region; W_{ij} indicates the spatial weight matrix.

Moran's I ranges from −1 to 1. When 0 < Moran's I ≤ 1, the provincial values of a specific attribute have a positive correlation and a tendency to spatial agglomeration. When the Moran's I value approaches or is equal to 0, no spatial autocorrelation exists in attribute-specific provincial values. When −1 < Moran's I < 0, the attribute-specific provincial values are negatively correlated. The statistic Z is used to test the significance level of Moran's I, i.e.:

$$z = \frac{I - E(I)}{\sqrt{VAR(I)}} \tag{3}$$

When the Z score is greater than 0 and is tested and found to be significant, that means a significant positive correlation exists in the spatial distribution of a specific attribute. When, however, the Z score is smaller than 0 and is tested and found to be significant, that means a significant negative correlation exists. Otherwise, no correlation exists.

2) Local spatial autocorrelation can decompose the Global Moran's I into various components, in order to test whether spatial agglomeration exists in local regions. The calculation formula is written as follows:

$$I_i = \frac{X_i - \bar{X}}{S}\sum_{j=1}^{N} W_{ij}(X_j - \bar{X}) \tag{4}$$

A positive I_i value means that there is either an area of high-high (HH) or low-low (LL) spatial agglomeration surrounding a region. A negative I_i value indicates either high-low (HL) or low-high (LH) spatial agglomeration.

2.3. β-Convergence test of provincial green development

Club convergence is the single biggest feature of China's regional development model. In other words, a strong spatial agglomeration effect of neighboring provinces exists. In economics, convergence is generally expressed by β-convergence or σ-convergence, which in turn target increments and stocks, respectively. Here, β-convergence is divided into absolute β-convergence and relative β-convergence. The former means that the level of green development in different provinces is negatively related to its initial level, with no consideration given to other conditions. The latter means that the level of green development varies among provinces. However, provinces tend to enter a steady state as time passes.

As this study investigates the changes of provincial green development over time, the demonstration model for testing absolute β-convergence is set as follows:

$$\frac{1}{T}\ln(green_{it+T}/green_{it}) = \beta_0 + \beta_1 \ln green_{it} + \mu_{it+T} \tag{5}$$

A spatial lag term is further added to examine whether or not spatial convergence of green development exists. Therefore, the formula is written as follows:

$$\frac{1}{T}\ln(green_{it+T}/green_{it}) = \beta_0 + \beta_1 \ln green_{it} + \rho W \ln(green_{it+T}/green_{it}) + \mu_{it} \tag{6}$$

wherein $green_{it}$ is the green development index; $\beta 1$ represents the absolute temporal convergence of provincial green development, and ρ represents the spatial convergence of provincial green development. In the later regression, the T value is taken as 1, which indicates the annual change of the green development index; W indicates the spatial weight matrix determined according to the rook principle, which in turn defines neighboring provinces based on common boundaries. When two provinces are adjacent, W = 1; otherwise, W = 0.

3. Spatial distribution of provincial green development

3.1. Spatial distribution of green development

The extreme value method is used to calculate the dimensionless value of different green development indicators. Table 1 displays the calculated annual provincial green development index from 2013 to 2016. The rankings of the 30 provinces in 2016 (in descending order) are as follows: Fujian, Zhejiang, Guangdong, Beijing, Shanghai, Yunnan, Hubei, Jiangsu, Hunan, Hainan, Jilin, Chongqing, Guangxi, Shandong, Jiangxi, Heilongjiang, Guizhou, Sichuan, Anhui, Gansu, Inner Mongolia, Hebei, Henan, Qinghai, Shaanxi, Tianjin, Ningxia, Xinjiang, Liaoning, and Shanxi. Generally, provincial green development shows a characteristic of spatial agglomeration. The areas with higher green development levels are mainly located in those eastern coastal provinces with more advanced economies, as well as the southwestern provinces with superior ecological endowments. The areas with low green development levels are mainly located in North China and Northwest China, which are inferior in terms of economic development and ecological endowments. According to the characteristics of all these regions, the eastern coastal provinces are referred to as the leading areas of green development, and the southwestern provinces as seen as the developing areas of green development.

3.2. Changes in regional green development

The calculated results of green development index of eastern, central and western regions (from 2013 to 2016) are shown in Figure 1. As a whole, the average green development indices of the 30 provinces over the four years were 52.04, 51.77, 52.51 and 53.05, respectively. Green development also presents an upward trend, except for a temporary decline in 2014. From a regional perspective, the overall green development trends in the eastern, central and western provinces were consistent with the national one. The green development index in the eastern region is significantly higher than the average of the country, the central region, and the western region. Also, the indices in the central region and western region are lower than the national average level. The central and eastern regions are gradually narrowing the gap in green development, and were far ahead of the western region in 2016.

In terms of growth rate, the green development indices present rise in 18 provinces during the period covered by our study, including Qinghai, Hebei, Shanghai, Xinjiang, Gansu, Zhejiang, Jiangxi, Henan, Fujian, Tianjin, Beijing, Jiangsu, Hunan Shanxi, Anhui, Yunnan, Heilongjiang, and Jilin; while at the same time the indices fell in 12 provinces, namely Liaoning, Chongqing, Guangdong, Inner Mongolia, Ningxia, Guizhou, Shaanxi, Hubei, Sichuan, Hainan, Guangxi, and Shandong. Overall, the green development indices increased in all but a very few provinces. In fact, the green development index grew by more than 10% in Qinghai, Hebei, and Shanghai, but it dropped sharply in Liaoning, Chongqing, and Guangdong.

3.3. Comparison with NBS results

In December 2017, NBS released *Bulletin on 2016 Annual Evaluation Results of Ecological Civilization*, which published the 2016 annual green development indices of 30 provinces in China for the first time. As indicated in the correlation diagram, a clear positive correlation exists between the calculations of our study and the NBS results. Also, most of the points are located around the fitted line, with no obvious outliers. Hence, the calculations are basically consistent with the NBS results, as shown in Figure 2. In other words, except for some major

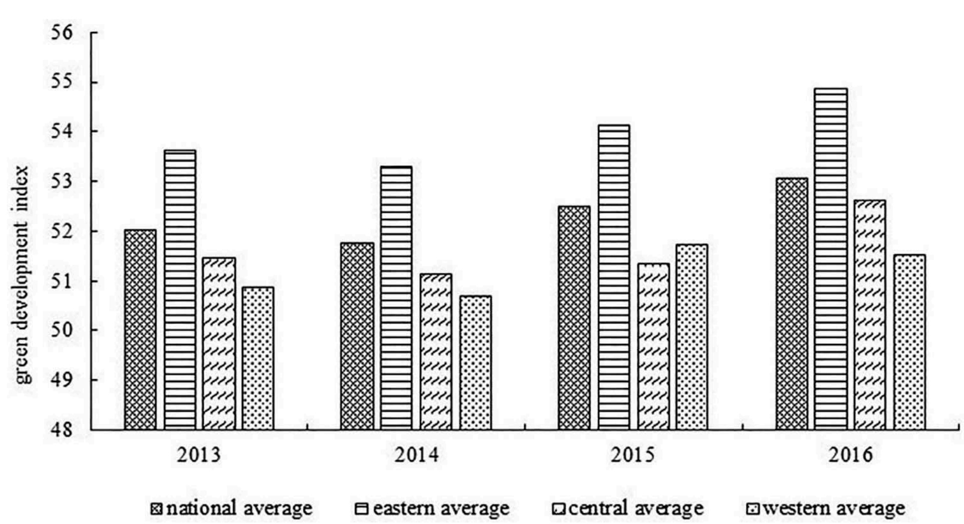

Figure 1. Changes of green development index in different regions.

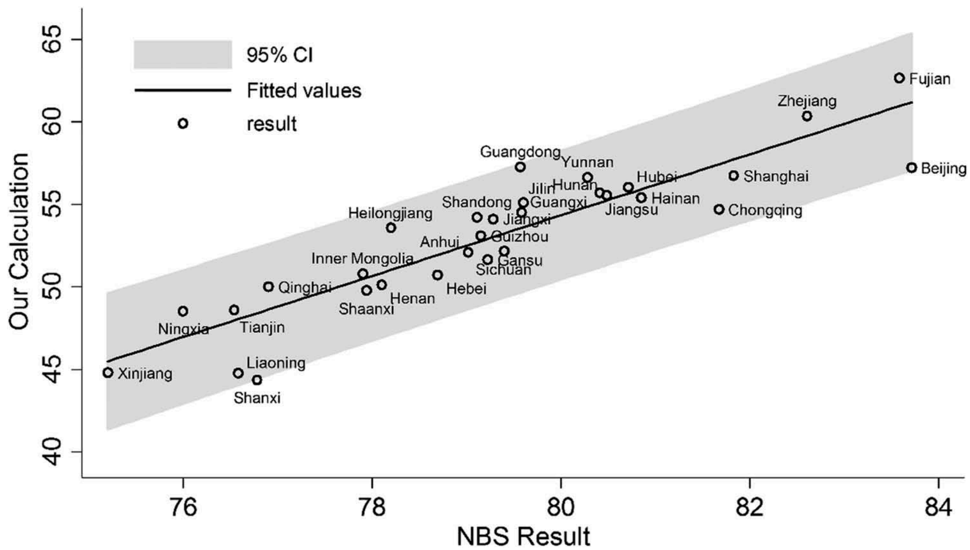

Figure 2. Comparison between our calculations and the NBS results.

changes in a very few provinces, the 2016 provincial rankings of the green development index identified by this study are basically consistent with the NBS rankings.

4. Spatial correlation analysis of green development

4.1. Global spatial autocorrelation

GeoDa1.10 was applied to test the spatial autocorrelation of the green development indices. The test was based on the 2013–2016 panel data of 30 provinces.[1] Then, the Global Moran's I value of the provincial green development indices was calculated. The spatial weight matrix was determined according to the rook matrix of first-order neighbors and the significance test conducted for Moran's I. The results of the test indicate that: the Moran's I value of provincial green development from 2013 to 2016 are all positive; the Z score is greater than zero, and the P value is less than 0.01. Also, the Moran's I tested to be significant. This result implies a significant effect of global spatial agglomeration in China's green development. However, Moran's

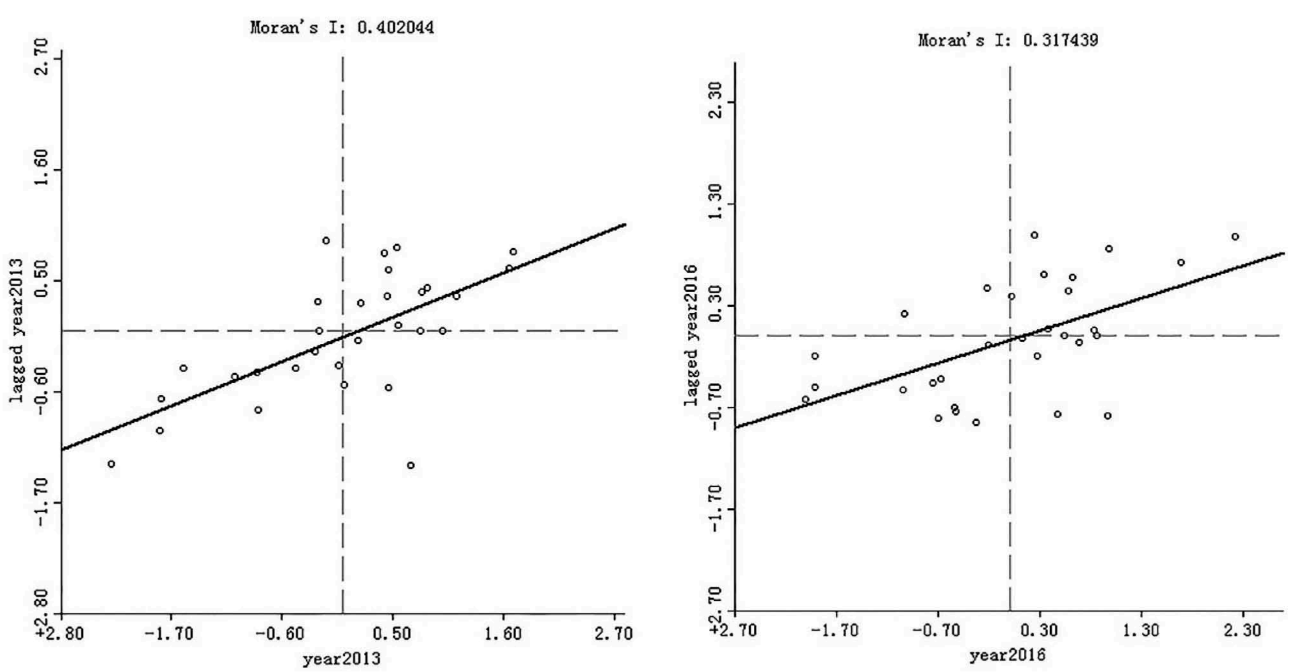

Figure 3. Moran's I scatter plots of the green development index in 2013 and 2016.

I exhibits a downward trend over time, and this is reflected in the continuous decline of the slope of the fitted line in the Moran's I scatter plot. This in turn indicates that the spatial agglomeration of green development continues to weaken, or more clearly, that green development has gradually become more balanced among regions, as shown in Figure 3.

4.2. Local spatial autocorrelation

The local Moran's I scatter plot was drawn to illustrate the spatial distribution of provincial green development during the period of 2013–2016 covered by our study. Provinces can be divided into four categories according to the four quadrants: 1) The first quadrant has HH agglomeration. This occurs where a region and its neighboring provinces have high levels of green development, and the spatial correlation is manifested as a diffusion effect. 2) The second quadrant has LH agglomeration. A region has a low level of green development but is surrounded by provinces with high levels of development. The spatial correlation is manifested as a transition area. 3) The third quadrant has LL agglomeration. A region and its neighboring provinces have low levels of green development, and the spatial correlation is manifested in low-level areas. 4) The fourth quadrant has HL agglomeration. A region has a high level of green development but is surrounded by provinces with low levels of development. The spatial correlation is manifested as a polarization effect.

As indicated in the local agglomeration of 30 provinces in 2016, an agglomeration of green development occurred in the HH and LL areas. The provinces included in the HH areas were Zhejiang, Fujian, Guangdong and Jiangxi. The LL areas included Inner Mongolia, Gansu, and Hebei. This finding indicates that the regions with high levels of green development were relatively concentrated in terms of geographical distribution, as was also the case with regions with low levels of green development. The HH areas were mainly located in the southeastern coastal regions. In these areas, the level of green development is relatively high, with obvious spatial agglomeration, due in large part to favorable ecological endowments. The LL areas are mainly found in northern China, such as Hebei and Inner Mongolia, where the provinces hold inferior ecological endowments and environmental quality, compared with others. They also suffer from low technological levels and industrial structures dominated by resource-intensive industries, all of which undermines growth quality.

Further, the methodology of taking the various types of spatial agglomeration over different time spans among the provinces was applied to reflect the spatio-temporal changes of provincial green development levels. The provinces could be divided into four categories, as follows: 1) The observed provinces move to neighboring quadrants. 2) The observed provinces move to quadrants that are not neighboring. 3) The observed provinces remain in the original quadrants and show spatial agglomeration. That implies that both the observed provinces and neighboring provinces hold either high or low levels of green development with only small differences between each other. 4) The observed provinces remain in the original quadrants, but they show spatial differentiation. In other words, the observed provinces contrast with and differ widely from their neighboring provinces in terms of the level of green development. In 2013 and 2016, provinces in the first quadrant were Jiangsu, Zhejiang, Fujian, Guangdong, Hainan, Hunan, Chongqing, Guangxi, Guizhou, and Yunnan. Only Anhui remained in the second quadrant. Provinces such as Hebei, Shanxi, Henan, Liaoning, Shaanxi, Qinghai, Gansu, Ningxia, and Xinjiang fell into the third quadrant. Lying in the fourth quadrant were Shandong, Beijing, and Hubei. It can be seen that the HH areas are mainly distributed in the eastern coastal provinces and the southwestern and eastern provinces, while the LL areas are located in the northern and northwestern provinces.

From 2013 to 2016, changes occurred in Shanghai (LH-HH), Jiangxi (LH-HH), Jilin (HH-HL), Heilongjiang (HH-HL), Tianjin (LL-LH), Sichuan (HL-LL), and Inner Mongolia (HL-LL). In terms of spatio-temporal changes, the spatial pattern of green development was relatively stable, with very few provinces experiencing changes. For example, Shanghai and Jiangxi have joined the "club" of high green development level provinces, while Inner Mongolia and Sichuan have been reduced to the status of low green development level "clubs." Jilin and Heilongjiang exhibited a favorable trend of green development relative to their neighbors, while Tianjin lagged behind its neighbors in terms of green development. The percentages of development change in all possible provinces can also reflect the spatial stability of specific attributes (Zhao et al. 2017). In this study, seven of the 30 (so 23.3%) studied provinces experienced varying degrees of change during the 2013–2016 period. This denotes the relative stability of the spatial distribution in green development.

4.3. Drivers of spatial autocorrelation

The above analysis reveals a continued reduction in the spatial correlation of provincial green development in China. In other words, the spatial agglomeration of provincial green development gradually weakened during the study period. What are the main factors that drive such changes? The study separately calculated the Moran's I value of the six categories of indicators (i.e. resource utilization, environmental governance, environmental quality, ecological protection, growth quality, and green life), so as to examine the causes of weaker spatial agglomeration through the changes of these indicators.

According to the Moran's I of different green development indicators in Table 2, the Moran's I value of resource utilization is relatively small. In fact, in most of cases, the value is not significant at all, which implies no obvious spatial agglomeration in this respect. The Moran's I of environmental governance showed a downward trend during the years covered by our study, declining from 0.528 in 2013 to 0.213 in 2015. This trend indicates a change in spatial distribution from an agglomerated status to a relatively balanced status. The Moran's I of environmental quality dropped from 0.573 in 2013 to 0.433 in 2016. This drop indicates that the spatial agglomeration of environmental quality tended to decline. However, regarding both ecological protection and growth quality, the Moran's I value showed an upward trend. This means that the spatial agglomeration of provincial growth quality became increasingly evident. The Moran's I value of green life was also on the rise from 2013 to 2015, before decreasing in 2016. The progress in the environmental field has served as the primary factor driving the gradual balance of provincial green development. In particular, the greatly reduced spatial agglomeration of environmental governance reflects the comparative improvement in provincial environmental governance.

5. Convergence analysis of green development

The level of green development varies widely among regions, which will in turn inevitably affect the changes in the spatial pattern of green development. Hence, a β-convergence analysis was conducted, in order to test the potential "club" phenomenon of green development in China (Lin and Huang 2011). Also, a spatial lag term was added to examine the changes in the spatial pattern. The spatial autoregressive model and spatial error model were adopted to test the panel data of green development in 2013–2016 in the 30 studied provinces. Based on Formula (6), the spatial error model is expressed as follows:

$$\frac{1}{T}\ln(green_{it+T}/green_{it}) = \beta_0 + \beta_1 \ln green_{it} + \mu_{it+T}, \mu_{it+T} = \varphi W + \varepsilon_{it} \quad (7)$$

Table 2. Moran's I in various green development indicators from 2013 to 2016.

Year	Resource utilization	Environmental governance	Environmental quality	Ecological protection	Growth quality	Green life
2013	0.119	0.528	0.573	0.414	0.310	0.264
	(0.091)	(0.001)	(0.001)	(0.001)	(0.001)	(0.005)
2014	0.011	0.475	0.560	0.419	0.310	0.283
	(0.294)	(0.001)	(0.001)	(0.001)	(0.001)	(0.005)
2015	0.143	0.213	0.441	0.417	0.332	0.308
	(0.059)	(0.015)	(0.001)	(0.001)	(0.001)	(0.001)
2016	0.049	0.483	0.433	0.435	0.339	0.275
	(0.186)	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)

Note: Brackets indicate statistical significance tests for P values.

Table 3. Convergence test of green development and its major indicators.

Item	Green development	Environmental governance	Environmental quality	Ecological protection	Resource utilization	Growth quality	Green life
Spatial autoregressive model							
ρ	0.0220	0.4203***	−0.0601	0.3312**	0.0108	0.4819***	0.1416
	(0.1147)	(0.0923)	(0.1380)	(0.1508)	(0.0899)	(0.0738)	(0.1342)
β	−1.1813***	−0.7520***	−0.7880***	−1.6522***	−1.3011***	−0.7152***	−0.3415***
	(0.0974)	(0.0920)	(0.0944)	(0.3978)	(0.0985)	(0.0940)	(0.1036)
N	90	90	90	90	90	90	90
R^2	0.1321	0.2841	0.1900	0.0004	0.3405	0.0007	0.2079
Spatial error model							
λ	0.2284*	0.6587***	0.3298**	0.3557**	0.4171***	0.6033***	0.4555***
	(0.1292)	(0.0864)	(0.1460)	(0.1544)	(0.1192)	(0.0897)	(0.1192)
β	−1.2229***	−1.0519***	−0.8623***	−1.6139***	−1.4140***	−0.7726***	−0.6138***
	(0.0994)	(0.0988)	(0.0977)	(0.3821)	(0.1014)	(0.1072)	(0.1317)
N	90	90	90	90	90	90	90
R^2	0.1340	0.2922	0.1876	0.0004	0.3404	0.0007	0.2158

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Brackets indicate the standard deviation.

In this formula, φ is a parameter that reflects the spatial correlation between residuals from regression.

According to the convergence regression equation, the ρ and β coefficients in Table 3 reflect the spatial and temporal convergence trends of provincial green development, respectively. The β coefficient is not significant, thereby denoting that no obvious trend of spatial agglomeration exists in provincial green development. In order to examine the factors that drive the convergence of green development, quantitative regressions were conducted for the indicators of six categories (i.e. resource utilization, environmental governance, environmental quality, growth quality, ecological protection, and green life). Firstly, the ρ coefficients for the regression on environmental quality, resource utilization, and green life were insignificant, thus implying no spatial convergence of green development in these aspects. The spatial convergence of environmental governance, ecological protection, and growth quality contributed most to the spatial convergence of green development. Secondly, the β coefficients for green development and its various indicators were significantly negative in this test, thus indicating temporal convergence in these aspects. There is a tendency for less developed regions are about to catch up with the leading regions in the area of green development. This is especially true in terms of ecological protection, resource utilization, and environmental governance. In addition, convergence "clubs" were found in the spatial distribution of green development. This finding could be mainly attributed to the spatial agglomeration of growth quality and the regional differences in ecological protection.

6. Conclusions and suggestions

In order to analyze the overall progress of China's green development, this study investigated the situation pertaining to green development in 30 provinces from 2013 to 2016. The analysis was conducted based on the GDIS released by NDRC, NBS, MEP and the CPC Organization Department, with some adjustments when it is appropriate. With the limited exception, provincial rankings of the green development indices in 2016 identified by this study were basically consistent with the one of NBS. Therefore, the results of our study are credible.

Through analysis, this study reached the following conclusions: Firstly, the overall level of green development in the 30 studied provinces has been on the rise. In fact, remarkable results have been achieved in terms of green development. In general, there were obvious spatial agglomeration and prominent regional differences in green development. The green development levels of eastern provinces were significantly higher than that of central and western provinces. Secondly, the gap in the provincial differences in green development gradually narrowed from 2013 to 2016. The comparative improvements in environmental governance served as the main factor that drove green development from agglomeration to balance. The agglomeration of economic growth quality coexisted with the balance in the field of ecological environment. This demonstrates that economic development and ecological environment became coordinated during the period covered by this study. Thirdly, provincial green development levels exhibited a clear trend of convergence in growth, in which the less developed provinces were observed to catch up with the more highly developed, leading provinces. Provincial convergence was also observed in changes to environmental governance and improvements in environmental quality. The overall progress in the environmental field has apparently stimulated the convergence of provincial green development levels over time.

The exercises conducted in the study contributes to a comprehensive understanding of the overall progress in China's green development since the 18th CPC National Congress, based on the conclusions mentioned as above, several policy implications can be drawn.

Firstly, the relevant indicators of ecological protection should be appropriately explored and revised, in which the progress in each specific province could be highlighted and an enhanced comparability of evaluation could be expected. The indicators of ecological protection in the current national Green Development Index System should be focused on the state of areas such as forest cover, grassland vegetation cover, and the area of nature reserves, etc. In the calculations of this study, ecological endowments conditions exert a significant impact on the provincial green development indices. Also, favorable ecological endowments are major contributors to some cases of ranking positions held by southwestern provinces such as Yunnan and Guizhou. The state indicators mainly reflect the background of provinces' ecological environments, rather than the positive progress made in the area of ecological protection. As a result, for some provinces with poor ecological endowments, their considerable progress in ecological protection is hardly to be reflected and included in these state indicators. This undermines the comparability of evaluation results, especially when a monitoring and evaluation system covers a relatively short period.

Secondly, a differentiated evaluation system should be developed based on the orientation of main functional areas to monitor and assess urban green development.

Provincial green development evaluations, which are based on relatively large geographical units, hardly reflect the sharp differences in ecological endowments and the functional orientations among the different areas within a province. The ecological environment indicators in the Green Development Index System are largely cross-administrative. These indicators are inapplicable to green development evaluation at the city level. This limits the evaluation of Green Development Index System only within a provincial level, therefore making it difficult to guide green development truly. The existing index systems built by some provinces to evaluate cities are deficient in terms of the cities' comparability with other regions in China. Therefore, it is necessary to develop a green development index system that can be used for monitoring and evaluating the green development level at a city level. Such a system defines the evaluation criteria and directions of green development in cities, while taking into account the differences in the orientation of the main functional areas simultaneously. By applying this method, the green development index system could help guide the construction of a "Beautiful China."

Thirdly, a high-quality development index system should reflect the relationship between "green" and "development" by incorporating the philosophy of green development into the systematical monitoring and evaluation. In the Green Development Index System, the "green" indicators are separated from the "development" indicators while it is difficult to make clear link between "green" and "development." And the related values of green transformation of the economic structure is in short in the indicators of growth. In the interest of promoting high-quality green development, three adjustments to the index system are suggested in order to reflect the levels and rate of green development well: 1) Adopt eco-environmental quality into restrictive indicators, so as to observe the "green" bottom line of high-quality development. 2) Adopt the indicators of green economic structure into the index system (such as the proportion of energy-intensive high-pollution industries, and the proportion of green industries, etc.), in order to show the environmental impact caused by the changes of economic structure. 3) Adopt the indicators of energy, resources, and environmental efficiency into the index system, in order to illustrate the resource and environmental costs of economic growth clearly.

Note

1. Not including Tibet, Hong Kong, Macau, and Taiwan due to the lack of data.

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