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Analysis of the interval difference and spatial effects of Chinese green economic progress

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Abstract

A green economy refers to a modern form of harmony between the environment and the economy. China showing the fastest economic growth in the world has entered into a new phase of advance, facing a critical industrial transformation and progression. The paper aims to analyse China's green economic development considering the differences in development of regions. The study applied the ultra-efficient slacks-based measure model to scrutinize China's green economic development efficiency. Dagum Gini coefficient and Kernel density methods are used to estimate spatial characteristics, local adjustments, and dynamic evolution trends. The analysis is based on an annual dataset of 30 Chinese provinces from 2010 to 2019. The findings did not confirm extensive China's green economic development. In contrast, the development efficacy reveals an influential drive over the years. Regional green development is detected as unstable and diverges due to interregional differences. The findings showed that environmental regulation, government investment, industrial structure, education development were 0.0648, 0.00154, 0.0035 and 0.118 (significant at 5% and 1%), respectively. Besides, they stimulate the green economic development in the analysed regions. However, urbanization and openness of economy had the negative value. It confirmed their restriction impact on the green economic development. In addition, the findings showed that ongoing Chines policy on management of environmental development is the priority direction and provoke the declining the environmental pollution. Besides, the modernization and optimization of the Chinese industry structure stimulate the further green economic progress.

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Green economy, super-efficiency SBM, Dagum Gini coefficient, Kernel density estimation, spatial effect

Introduction

People have also had new thinking about the green economy to achieve justifiable progress.[1–5] The green economy's development is divided into three stages: first, from 1989 to 2000, its importance was recognized, but the consideration was to make the ecological environment better by following relevant economic procedures; second, from 2007 to 2009, people's understanding about the green economy began to deepen.[6–9] From 2010 onwards, it is argued as inevitable that it brings happiness to humankind, regulates the inconsistency/paradox amid economic development and ecological environment, and must achieve a harmonious and unified model.

On February 22, 2021, the State Council issued the "Guiding Opinions on Accelerating the Establishment and Improvement of the Green and Low-Carbon Circular Development Economic System".[10] It establishes and improves the economic system's green and low-carbon circular development. Besides, it states in line with the requirements of the development of the times, accelerates the construction of ecological and environmental protection work, promotes the formation of green production and lifestyle, and the overall deployment of accelerating the establishment and improvement of the green and low-carbon circular development of the economic system, aiming to coordinate the relationship between economic development and ecological, environmental protection construction, and promote the comprehensive green transformation of economic and social development. Build a modernization and harmony for man and nature to coexist

Currently, China's economy is facing a critical industrial transformation and progression.[11–13] In unison, the erection of ecological refinement has also undergone historical and overall changes. The efficiency of energy resource utilization is not high, the effectiveness of ecological environment governance is not stable, and the task of achieving carbon peak carbon neutrality is arduous.[14–18] In this regard, through the analysis of the interval difference between the competence of China's green economy development, the study could better grasp the development position, further encourage a low-carbon globular economy, and build a harmonious society to live in.

The notion of "green economy" was formally proposed by the famous economists Pearce D., Markandya A., Barbier E., and Caprotti F. defined the concept of a green economy in detail, arguing that the green economy is closely related to sustainable development,[19–23] and some scholars believe that the green economy itself is a controversial subject.[24] It presents new theoretical and experiential tasks for social scientists and impending environmental research.[25] The European Union (EU) prioritizes promoting green development, starting with significant renewable energy paths, carbon emission swapping systems and energy-saving novelty tactics.[26] The study[27] divided countries by the income (developed and developing countries). The findings[27] confirmed different regressors" (capital, labour, renewable energy ad technological innovations) impact on the country's economic growth. It provoked countries to sustainable development, especially in the post-COVID-19 era.

China has entered into a new phase of advance. The concept of green expansion offered by General Secretary Xi Jinping can well encounter significant changes in the structure of social practice and the needs of the new paradigm of national governance.[28] Through the scenario simulation analysis of the system dynamics model, it is found that by taking the green development path, China can achieve better quality economic growth.[29]

Generally, the index geographically weighted regression (GWR) model employed to find the level of green economy development has improved in China nationwide. The overall development level shows a state of "east, high, high, and west low".[30] China's green total factor productivity (GTFP) exposed a rising tendency, with an average of 3.37% annual growth rate. The regional differences in green development generally show an upward trend of "N" type fluctuations, and there are regional differences. Furthermore, the wide-ranging modifications mainly stem from the differences between regions, followed by regional differences and super variable density contributions.[31] In addition, a weighty spatial positive correlation exists in the efficiency of China's provincial green economy.[30–32] The green economy efficiency level in the east is maximum and minimum in the central region, and there is a spatial unqualified β convergence in each region.[33]

The efficiency of the green economy and gross domestic product (GDP) show the opposite trend, which to a certain extent shows a positive correlation between current economic growth and environmental pollution in China and still occurring on the left side of the environmental Kuznets curve.[34] Green economy strategies might not reduce environmental degradation and poverty without considering cultural, economic, and political constraints.[35] China's green economic development is limited by factors such as the lock-in of traditional industries, the slow cultivation of the domestic market in emerging green industries, the weak domestic demand, and the distortion of resource and environmental prices and values.[36] Some scholars study the relationship with the green economy from multiple perspectives, such as financial leverage,[37] economic agglomeration,[38] environmental regulation, market potential[39] and etc.

The studies[19, 40, 41] confirmed that the environment and the economy should interact, and a "sustainable economy" should be established on social and ecological conditions. A green economy refers to a modern form of harmony between the environment and the economy. The manufacturing economy produces a state of development and exposes human-environmental safety and healthiness. Under the green economy model, many technologies, such as environmental fortification and cleaner production processes, are converted into productive forces. Economic behaviours not confronting the environment are operated to accomplish sustainable economic growth. According to the definition of a green economy, the factors affecting the expansion of a green economy primarily include social development, environmental regulation, technological progress, industrial structure and energy structure, and foreign investment activities.

The study[42] applied composite-based structural equation model (CB-SEM) to confirm that environmental regulation policies is the core trigger of the circular economy, including in Era of COVID-19 for Ecaudor. Besides, the findings confirmed that nformation technologies led to increasing of efficient use of resources.

Environmental quality is the attribute of a public good, which determines that the maintenance of environmental quality mainly depends on government actions.[13, 14] Government intervention in environmental quality is called environmental regulation. The classical economic theory believes that the burden on enterprises will be increased by environmental regulation, resulting in an uncoordinated contradiction with the development.

The Porter hypothesis suggested that in the short term, the production cost of enterprises will increase. It justified that the reasonable and adequate environmental regulations could force enterprises to carry out technological transformation. In the long run, it can diminish the production cost, improve the productivity level, and then promote the development of the green economy.

Hypothesis 1: There is a positive and direct association between environmental regulation and green economic development.

Innovation-driven is to endorse the old-fashioned to the green development model conversion, promote the integration, reorganization and optimization of production factors, make resources and factors advanced, enhance total factor productivity, eliminate backward productivity, processes and products, transform and upgrade traditional industries, yield high-ended and high-value-added goods and amenities, create new economic growth points, and achieve economic aggregate increase and industrial structure optimization. Innovation and development are inseparable from the government's financial support,[2, 3, 43–45] investment in research and development (R&D). Innovation-driven green economy high-quality development is reflected in knowledge in green development,[46–48] the use of new or improved technology, breaking through resource constraints, improving resource utilization, realizing the green transformation and transformation and upgrading of traditional industries, producing sanitary products, developing green industries and circular economy, effectively reduce the use of resources and pollution. Besides, it allows achieving sustainable environment-friendly development.

Hypothesis 2: Government financial input and the green economy are positively interrelated.
Hypothesis 3: Education is also positively correlated with eco-friendly economic development.

The growth of the green economy is affected by social development. Social development[7, 49] be affected by different factors such as the tertiary industry share, urbanization development, and the level of opening up. Urbanization is one of the crucial ways to modernization, a significant mode to deal with agriculture-related concerns, sponsoring synchronized regional development, enhancing inland demand and industrial up-gradation, and extensive historical consequences intended for building an abstemiously well-off society all-round way and accelerating the promotion of socialist modernization. Urbanization is mainly manifested as the flow of rural population to cities and towns, resulting in a severe shortage of urban carrying capacity and aggravating environmental pollution, resource shortage, etc.[38, 50]

The tertiary industry is mainly based on the service industry. It is conducive to vigorously evolving the tertiary industry, enhancing the agricultural productivity, and optimizing the manufacturing structure, thereby endorsing rapid, continued and vigorous development of the whole economy.[11, 13] Vigorously implementing the favouring and opening-up policy to the world is advantageous to attracting foreign investment, introducing advanced technologies, developing production, and achieving qualitative development.

Hypothesis 4: The industrial optimization upgrading is positively correlated with the growth of a green economy
Hypothesis 5: Urbanization is negatively related to the growth of an environmentally favourable economy
Hypothesis 6: The opening-up level and green economy development are positively correlated.

The paper aims to analyse China's green economic development considering the differences in development of regions On the contrary with previous investigations,[51–53] the study applied the spatial effect of green economic development efficiency. It allowed better analyzed to derive the main influencing factors of the regional green economy.

The paper contributes to the existence investigation in few ways: 1) to develop the approach to integrated development tendency of the Chinese green economic development efficiency based on super-efficient SBM model; 2) highlighted the gap between regional green economic development of China using the Dagum Gini coefficient and its decomposition method; 3) to estimate the nuclear energy development, distribution dynamics, and absolute difference evolution between the four regions of China using the nuclear density estimation method; to estimate the spatial spillover effect of efficiency of green economic development based on a spatial metric model.

The paper contains the following sections: introduction – highlighted the actuality of the isuuse, analysis of theoretical frameworks of Chinese green economic progress and justification of hypothesis; material and methods – explain the approached to check the hypothesis; results – describe the core findings on Chinese green economic development; discussion and conclusion – analyse the key findings and recommendations to improve China's green economic development and promote the coordinated development of the regional green economy.

Material and methods

The longitudinal data of 30 Chinese provinces from 2010 to 2019 was used as the study sample (Tibet, Macao, Hong Kong, and Taiwan excluded). The data for analysis were obtained from the Statistical Yearbooks of Science and Technology, Environment and Yearbook of each province.[54,55]

The study used the following interpreted variables: Efficiency of Green Economy Development. Using the super-efficient slack-based model (SBM), the input, expected output and undesirable output indicators are calculated by scholars D. Yulong.[56] Input indicators include capital investment, labour input, and energy input. Among them, capital input is expressed in capital stock. According to the formula, the capital stock[57] is measured by the perpetual inventory method, indicating the capital stock of the current period, indicating the capital stock of the previous period, indicating the amount of investment, selecting the total amount of fixed asset formation in each province. It indicates that the depreciation rate is set at 9.6%, deflating the capital stock in 2009 as the base period. The employed population represents labour input. The annual electricity consumption expresses energy input because the GDP elastic value of electricity demand is close to that of energy demand.[58–60] Expected output, expressed by GDP and converted from nominal GDP to real GDP as expected output; non-expected output, selects representative industrial soot and sulfur dioxide emissions, wastewater discharges, and comprehensive pollution indexes in exhaust gases.

The study used the following explanatory variables: environmental regulation, the academic community on the command-control type environmental regulation agent variables mostly choose a single variable, including the amount of pollution control investment, the number of environmental regulations, the number of environmental protection agency staff, the treatment rate of each pollutant, etc. Some scholars[61, 62] to build a comprehensive evaluation index system using the entropy method to measure. This paper through the construction of the indicator system using the entropy method to measure; government input, with the proportion of fiscal expenditure to the proportion of fiscal revenue; industrial structure, to the tertiary industry output value occupies the proportion of the GDP of the city The level of urbanization is measured by the proportion of the regional urban population in the total population; the level of opening up to the outside world is measured by the proportion of the total import and export volume of the region to the regional GDP; and the level of education development is measured by the ratio of the number of college students in the region to the total population of the region.

Table 1. Descriptive statistics.

Variable	Symbol	Obs	Mean	Std.Dev.	Min	Max
The efficiency of green development	*GE*	300	1.456	0.384	1.013	3.628
Environmental regulation	*ER*	300	0.525	0.533	0	2.585
Government investment	*Gov*	300	24.563	10.220	10.582	62.835
Industrial structure	*Ind*	300	45.711	9.760	28.615	83.521
Urbanization level	*Urb*	300	57.054	12.463	33.81	89.6
Open the door to the outside world	*Open*	300	5.100	9.524	0.005	70.123
Education development	*Edu*	300	1.928	0.502	0.799	3.453

The findings of descriptive statistics of the selected variables is shown in Table 1.

Undesirable output – super-efficiency model. The super-efficiency model is a method of evaluating the Data envelopment analysis (DEA) as effective or weakly effective. The principle is to exclude the evaluated decision-making unit's (DMU) from the reference set so that the efficiency value obtained by the solution may be greater than 1. Considering both "undesirable output" and "super efficiency", combining the undesirable output-SBM model and the super-efficient SBM model, drawing in the studies.[63] Methods for constructing super-efficient SBM models that contain undesirable outputs. Assuming that the production activities of each province obtain a variety of expected and undesirable outputs through multiple production factor inputs, the production possibility set containing undesirable outputs is constructed. Then each province is used as a decision-making unit in the calendar year to set the optimal production technology frontier. The set of environmental technologies that define the efficiency of measuring the efficiency of green economic development, i.e., the set of production possibilities, is:

$$PPS = \left\{ X, \overline{Y^g}, \overline{Y^b} | \bar{X} \geq \sum_{\substack{j=1 \\ j \neq 0}}^{L} \lambda_j X_j, \overline{Y^g} \leq \sum_{\substack{j=1 \\ j \neq 0}}^{L} \lambda_j y_j^g, \overline{Y^b} \geq \sum_{\substack{j=1 \\ j \neq 0}}^{L} \lambda_j y_j^b L \leq e\lambda \leq \mu, \lambda_j \geq 0 \right\} \quad (1)$$

where PPS – the input-output mode of each city corresponds to m species input, s_1 – expected output and s_2 – unexpected outputs; X – dimensional input vector, Y^g and Y^b the expected and unexpected output vectors of s_1 and s_2 dimensions, respectively $X = (x_1, x_2, \ldots, x_L) \in R_+^m$ 、 $Y^g = (y_1^g, y_2^g, \ldots, y_L^g) \in R_+^{s_1}$、 $Y^b = (y_1^b, y_2^b, \ldots, y_L^b) \in R_+^{s_2}$, – means the heavy vector of rights protection.

When L = 1, μ = 1, the scale remuneration of producing green technology is variable; when L = 0, μ = ∞, it indicates that the production process scale remuneration remains unchanged. $s^- \in R_+^{s_m}$ is the excessive input vector, $s^b \in R_+^{s_2}$ is excessive undesired output, $s^g \in R_+^{s_1}$ It is the insufficient expected output. The undesired output-super-efficiency model can be derived from the ultra-efficiency SBM model, which is constructed as:

$$\begin{cases} \rho = \min\limits_{\lambda,\overline{x},y^g,y^b} \dfrac{\sum_{i=1}^{m} \dfrac{\overline{x_t}}{x_{io}}}{\dfrac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1} \dfrac{\overline{y_r^g}}{y_{r0}^g} + \sum_{k=1}^{s_2} \dfrac{\overline{y_k^b}}{y_{k0}^b}\right)} \\ s.t. X \geq \sum\limits_{\substack{j=1 \\ j\neq 0}}^{L} \lambda_j x_j \\ \overline{Y^g} \leq \sum\limits_{\substack{j=1 \\ j\neq 0}}^{L} \lambda_j y_j^g \\ \overline{Y^b} \geq \sum\limits_{\substack{j=1 \\ j\neq 0}}^{L} \lambda_j y_j^b \\ \bar{X} \geq x_0, \overline{Y^g} \leq y_0^g, \overline{Y^b} \geq y_0^b \\ \overline{Y^g} \geq 0, \overline{Y^b} \geq 0, L \leq e\lambda \leq \mu, \lambda_j \geq 0 \\ \overline{x_t} = x_{i0} + s^-(i, \ldots, m) \\ \overline{y_r^g} = y_{r0}^g - s^g(r=1, \ldots, s_1) \\ \overline{y_k^b} = y_{k0}^b - s^b(k=1, \ldots, s_2) \end{cases} \tag{2}$$

where $\overline{x_t}, \overline{y_r^g}, \overline{y_k^b}$ – the projection value of the input and output of the evaluated unit, that is, the target value; x_{i0} 、 y_{r0}^g、 y_{k0}^b – the corresponding original values.

Dagum Gini coefficient and decomposition method. Dagum C.[64, 65] decomposed the Gini coefficient into intra-region differences, the net difference between regions, and super variable density contribution. The latter two constitute the total contribution of differences between regions. It represents the complete Gini coefficient, and the larger the value indicates, the more significant the overall gap in green economy development efficiency in China. It can also be disintegrated into the contribution of hypervariable density. The specific formula is as follows:

$$G = \frac{\sum_{j=1}^{k} \sum_{h=1}^{k} \sum_{i=1}^{n_j} \sum_{r=1}^{n_h} |y_{ji} - y_{hr}|}{2n^2 \bar{y}} = G_w + G_{nb} + G_t \tag{3}$$

where y_{ji} 、 y_{hr} – the green economy development index of the province i and the r province in the j and h region, $\bar{y}$ – the middling of the national green economy development level, n and $n_j(n_h)$ are for the number of the provinces, and the number of provinces within the region, respectively.

Firstly, the mean value of the green economy is utilized to rank each region:

$$\bar{Y}_h \leq \cdots \leq \bar{Y}_h \cdots \leq \bar{Y}_k \tag{4}$$

Secondly, the Gini coefficient is mainly divided into inter and intra-regional differences:

$$G_{jj} = \frac{\frac{1}{2\bar{Y}_j} \sum_{i=1}^{n_j} \sum_{r=1}^{n_j} |y_{ji} - y_{hr}|}{n_j^2} \tag{5}$$

$$G_w = \sum_{j=1}^{k} G_{jj} p_j s_j \tag{6}$$

$$G_{jh} = \frac{\sum_{i=1}^{n_j} \sum_{r=1}^{n_h} |y_{ji} - y_{hr}|}{n_j n_h (\bar{Y}_j + \bar{Y}_h)} \tag{7}$$

$$G_{nb} = \sum_{j=2}^{k} \sum_{h=1}^{j-1} G_{jh}(p_j s_h + p_h s_j) D_{jh} \tag{8}$$

$$G_t = \sum_{j=2}^{k} \sum_{h=1}^{j-1} G_{jh}(p_j s_h + p_h s_j)(1 - D_{jh}) \tag{9}$$

where G_{jj} – the Gini coefficient of the j region and contributes to the $G_w the$ regional difference; G_{jh} – interregional of the j, h region; D_{jh} – the relative influence of green economy development and contributes to the hypervariable density of G_t.

Finally, to calculate the relative impact of green economy development:

$$G_{jh} = \frac{d_{jh} - p_{jh}}{d_{jh} + p_{jh}} \tag{10}$$

$$d_{jh} = \int_0^{\infty} dF_j(y) \int_0^{y} (y - x) dF_h(x) \tag{11}$$

$$p_{jh} = \int_0^{\infty} dF_h(y) \int_0^{y} (y - x) dF_j(x) \tag{12}$$

where $p_j = p_j / n$, $s_j = n_j \overline{Y_j} / n\bar{Y}$, $j = 1, 2, \cdots, k$; d_{jh} – defined as the difference in the green economic development indicators between regions, p_{jh} – the first-order moment.

Kernel density estimation. To better replicate the dispersal dynamics and evolution law of the absolute difference in green economy development in the country and the four regions, the position, situation, extension and polarization trend of the comprehensive index in the four regions in China and the nuclear density estimation method is analyzed. The hypothesis is the density function of China:

$$f(x) = \frac{1}{Nh} \sum_{i=1}^{N} K(\frac{X_i - x}{h} \tag{13}$$

where N – the number of observations, X_i – independent, x – equally distributed observations, representing the average of the observed values, $K(\cdot)$ – a kernel density function and a bandwidth.

The smaller the bandwidth, the estimated accuracy is higher. This research applies the following Gaussian kernel density function to estimate the dynamic distribution evolution of the country's comprehensive green economy development index and the four regions.

$$K(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) \tag{14}$$

Model construction. For investigating the spatial interaction and spillover effect of green economy development, the Moran's I index should be used for spatial correlation. The formulation is as under:

$$\text{Moran's } I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j}(Y_{it}-\bar{Y})(Y_{jt}-\bar{Y})}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j}} \tag{15}$$

where $w_{i,j}$ – the weight matrix defined above, $\bar{Y}$ – the mean, Y_{it} and Y_{jt} – progress level of the green economy in year t of i and j provinces, respectively.

The local Moran index is calculated as follows:

$$\text{Local Moran's } I_i = \frac{(Y_{jt}-\bar{Y})}{S^2}\sum_{j=1}^{n} w_{i,j}(Y_{jt}-\bar{Y}) \tag{16}$$

The Moran's I index value ranges between −1 to 1 as [-1,1].

Spatial weight matrix. Professor Waldotobler argued that things are connected in the 1st law of topography. The first task of spatial econometrics is to establish a weight matrix to calculate the spatial correlation of economic variables. The weight matrix is divided into adjacent space weight, geospatial matrix, economic space matrix, and nested matrix. The Adjacency space matrix, a simple binary weight matrix, is as below:

$$W_{i,j} == \begin{cases} 1, & i = j \\ 0, & i \neq j \end{cases} \tag{17}$$

In the geospatial matrix, Wang Shoukun (2013) proved nearer the distance between the two regions, the greater the weight, which is set as follows:

$$W_{i,j} = \begin{cases} \frac{1}{d_{ij}}, & i \neq j \\ 0, & i = j \end{cases} \tag{18}$$

where $W_{i,j}$ – the transportation distance between the two provincial capitals, reflecting the cities" social and economic development relationship.

Economic, spatial matrix and geographical factors are not the only ones leading to spatial effects. Based on the inverse distance matrix, the economic matrix is expressed as follows:

$$W_{i,j} = \begin{cases} \frac{1}{|Y_i - Y_j|}, & i \neq j \\ 0, & i = j \end{cases} \tag{19}$$

where Y_i – the economic variable i region; Y_j – in j, as measured by per capita GDP.

Nested matrix, taking into account both geographical and economic factors. The nested matrix is represented as given lower:

$$W_{i,j} = \begin{bmatrix} \frac{1}{d_{11}} & \cdots & \frac{1}{d_{1n}} \\ \vdots & \ddots & \vdots \\ \frac{1}{d_{n1}} & \cdots & \frac{1}{d_{nn}} \end{bmatrix} \begin{bmatrix} \frac{x_{11}}{x} & \cdots & \frac{x_{1n}}{x} \\ \vdots & \ddots & \vdots \\ \frac{x_{n1}}{x} & \cdots & \frac{x_{nn}}{x} \end{bmatrix} \tag{20}$$

where d – the geographical distance weight matrix, which measures the geographical location; X – the economic characteristic of the region while inspecting, using the average per capita GDP.

Spatial measurement models. Consider different spatial effects and introduce interregional interactions into the model. To obtain the best fitting effect, consider establishing a spatial autoregressive (SAR), spatial error model (SEM) and a Spatial Durbin (SD) models, respectively, and then determine the most suitable model through various tests for empirical analysis.

Spatial autoregression model (SAR):

$$y = \lambda Wy + X\beta + \varepsilon \tag{21}$$

where Y – the high-quality development level of China's economy; W – the spatial weight matrix, and the X – the n * k data matrix, the corresponding coefficient and the regression coefficient.

Spatial Error Model (SEM). The error terms can reflect Spatial dependence, which builds the SEM.

$$\begin{cases} y = X\beta + \varepsilon \\ \mu = \rho M\mu + \varepsilon \text{ , } \varepsilon \sim N(0, \sigma^2 \ I_n) \end{cases} \tag{22}$$

where M – a spatial weight matrix, representing the SE coefficients, x, y.

SD Model:

$$y = \lambda Wy + X\beta + WX\delta + \varepsilon \tag{23}$$

where W, X, δ – the effect of variables in adjacent regions, x, y.

The Spatial Durbin model effect decomposition. Decomposing the spatial effects of the SD model results in a formula representation of the model's total, direct, and indirect effects. The SD model is generally taken as:

$$y = \alpha Wy + X\beta + WX\delta + \tau_n\varphi + \omega \tag{24}$$

$$(I_n - \alpha W)y = X\beta + WX\delta + \tau_n\varphi + \omega \tag{25}$$

$$y = (I_n - \alpha W)^{-1}(X\beta + WX\delta) + (I_n - \alpha W)^{-1}(\tau_n\varphi + \omega) \tag{26}$$

$$V(W) = ((I_n - \alpha W)^{-1}) = I_n + \alpha W + \alpha^2 W^2 + \alpha^3 W^3 + \cdots \tag{27}$$

Then:

$$y = V(W)(X\beta + WX\delta) + V(W)(\tau_n\varphi + \omega) \tag{28}$$

$$\begin{aligned} X\beta &= \begin{pmatrix} \sum_{r=1}^{k} x_{1r}\beta_r \\ \sum_{r=1}^{k} x_{2r}\beta_r \\ \vdots \\ \sum_{r=1}^{k} x_{nr}\beta_r \end{pmatrix} \\ &= \begin{pmatrix} \beta_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \beta_1 \end{pmatrix} \begin{pmatrix} x_{11} \\ \vdots \\ x_{n1} \end{pmatrix} + \begin{pmatrix} \beta_2 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \beta_2 \end{pmatrix} \begin{pmatrix} x_{12} \\ \vdots \\ x_{n2} \end{pmatrix} + \cdots\cdots + \begin{pmatrix} \beta_k & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \beta_k \end{pmatrix} \\ &\times \begin{pmatrix} x_{1k} \\ \vdots \\ x_{nk} \end{pmatrix} \end{aligned} \tag{29}$$

$$I_n\beta_1 x_1 + I_n\beta_2 x_2 \ + I_n\beta_k = \sum_{r=1}^{k} l_n\beta_r x_r \tag{30}$$

The exact mode of reasoning is available as follows:

$$WX\delta = W\sum_{R=1}^{K} I_n\delta_r x_r \tag{31}$$

Sorted out:

$$\begin{aligned} y &= V(W)\left(\sum_{r=1}^{k} I_n\beta_r x_r + W\sum_{r=1}^{k} I_n\delta_r x_r\right) + V(W)(\tau_n\varphi + \omega) \\ &= \sum_{r=1}^{k} V(W)(I_n\beta_r + W\delta_r)x_r + V(W)(\tau_n\varphi + \omega) \end{aligned} \tag{32}$$

Order:

$$S_r(W) = V(W)(I_n\beta_r + W\delta_r \tag{33}$$

$$y = \sum_{r=1}^{k} S_r(W)x_r + V(W)\tau_n\varphi + V(W)\omega \tag{34}$$

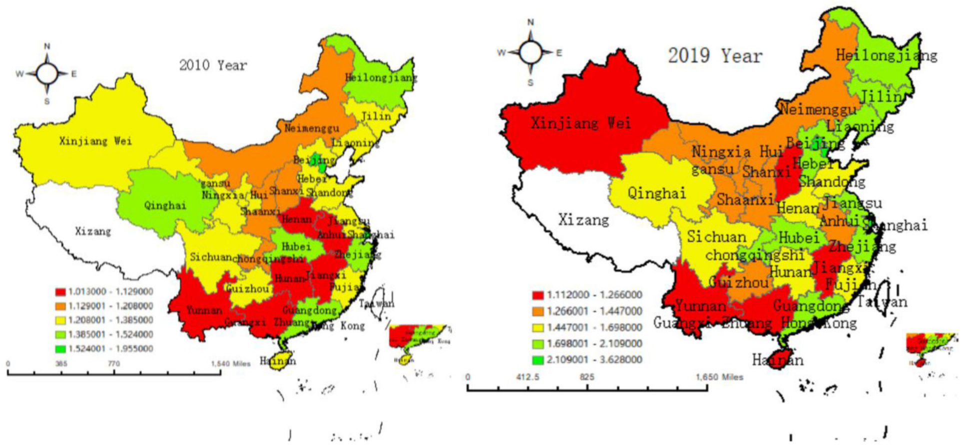
$$\begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{pmatrix} = \sum_{r=1}^{k} \begin{pmatrix} S_r(w)_{11} & \cdots & S_r(w)_{1n} \\ \vdots & \ddots & \vdots \\ S_r(w)_{n1} & \cdots & S_r(w)_{nn} \end{pmatrix} \begin{pmatrix} x_{1r} \\ \vdots \\ x_{nr} \end{pmatrix} + V(W)(\tau_n\varphi + \omega) \tag{35}$$

where $\frac{\partial y_i}{\partial x_{ir}} = S_r W_{ii}$ – the direct effect, indicating the average degree of the change of the r variable on the local explained variable, $\frac{\partial y_i}{\partial x_{jr}} = S_r \ W_{ij}$ – the indirect effect reflecting the average degree of the change of the r variable on the explained variable in the adjacent area, the sum of the two is the total effect.

Results

Change trend of green economy development efficiency. Considering findings, China's overall green economy development level is not high, but the development efficiency index increases yearly.

We can find from the Figure 1(a) and (b) that the provinces had a high level of green economy development in 2010, including Beijing, Guangdong, Shanghai, Zhejiang, Hubei, Qinghai and Heilongjiang, and the efficiency of green economy development is all at a low level, indicating that for achieving rapid economic growth, environmental protection is neglected. There are many industrial enterprises in the central, which affects the development of the green economy; most western regions develop slowly, and their development efficiency is at a medium level. In 2019, the development efficiency of the green economy in China was significantly improved, most provinces with high-level development increased, and the number of provinces with low-level development decreased, indicating that China also attaches importance to environmental protection while achieving high-quality economic development.



(a) (b)

Figure 1. Spatial distribution map of China's green economy development. (a) visualization for the 2010 year. (b) visualization for the 2019 year.

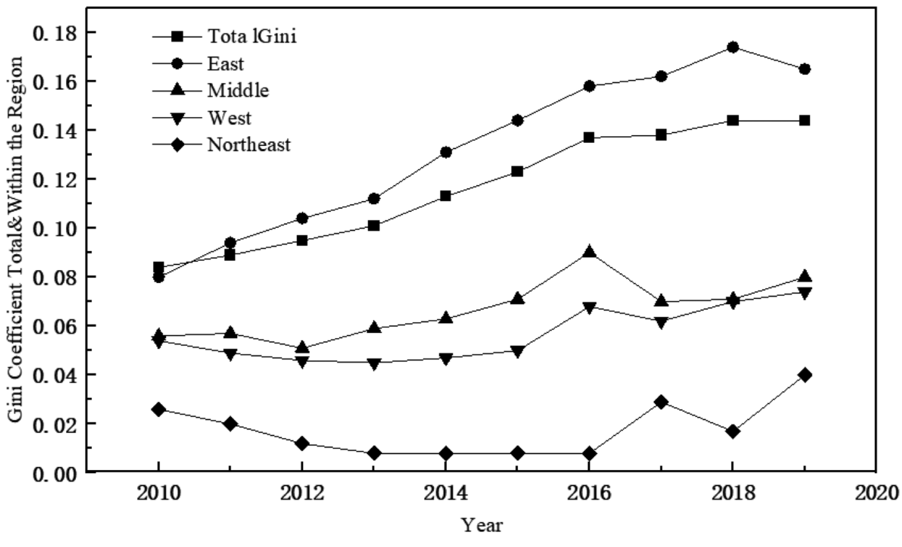


Figure 2. Overall and intra-regional differences in green economy development in 2010–2019.

We used formula (3) – (12) to calculate the Gini coefficient of the development of the green economy. The results indicate that the development of China's green economy has severe regional imbalances. The Gini coefficient of green economy development is decomposed into regions and between regions to analyze the regional differences better, as shown in Table 2.

Regional differences in the development of green economies. From Figure 2, it can be seen that, in general, with the continuous improvement and promotion of the coordinated development mechanism of the regional economy from 2010 to 2019, the overall regional gap in China's green economic development has widened year by year.

Table 2. Gini coefficient and its decomposition results in green economy development in China.

Indicators		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total Gini		0.084	0.089	0.095	0.101	0.113	0.123	0.137	0.138	0.144	0.144	0.117
Gini Coefficient Within the Region	East	0.080	0.094	0.104	0.112	0.131	0.144	0.158	0.162	0.174	0.165	0.133
	Middle	0.056	0.057	0.051	0.059	0.063	0.071	0.090	0.070	0.071	0.080	0.067
	West	0.054	0.049	0.046	0.045	0.047	0.050	0.068	0.062	0.070	0.074	0.056
	Northeast	0.026	0.020	0.012	0.008	0.008	0.008	0.008	0.029	0.017	0.040	0.018
Interregional Gini Coefficient	East-Middle	0.138	0.148	0.157	0.165	0.180	0.193	0.205	0.203	0.204	0.185	0.178
	East-West	0.097	0.107	0.117	0.128	0.149	0.162	0.175	0.184	0.192	0.194	0.150
	East-Northeast	0.072	0.080	0.089	0.093	0.107	0.115	0.126	0.123	0.127	0.123	0.106
	Middle-West	0.072	0.071	0.070	0.072	0.070	0.074	0.090	0.072	0.074	0.081	0.075
	Middle -Northeast	0.085	0.090	0.092	0.101	0.106	0.116	0.129	0.136	0.136	0.134	0.113
	West-Northeast	0.049	0.048	0.050	0.056	0.064	0.076	0.087	0.113	0.121	0.147	0.081
Contribution value	within the region	0.019	0.020	0.021	0.022	0.025	0.028	0.032	0.032	0.034	0.034	0.027
	Inter-regional	0.055	0.060	0.065	0.068	0.077	0.083	0.085	0.090	0.090	0.089	0.076
	Super variable density	0.010	0.009	0.009	0.010	0.011	0.013	0.019	0.016	0.019	0.021	0.014
Contribution Rate （%）	within the region	22.62	22.47	22.11	21.78	22.12	22.76	23.36	23.19	23.61	23.61	23.08
	Inter-regional	65.48	67.42	68.42	67.33	68.14	67.48	62.04	65.22	62.50	61.81	64.96
	Super variable density	11.90	10.11	9.47	9.90	9.73	10.57	13.87	11.59	13.19	14.58	11.97

The regional difference is the largest in the northeast region, and the gap is the fastest and the slowest in the western region. Specifically, the mean Gini coefficient was 0.08, from 0.08 in 2010 to 0.174 after 2011. The difference was 0.067 and 0.056, respectively, decreasing in the central than the western region from 2010 to 2016 and decreasing after 2016. The average difference in the northeast region was 0.018, which decreased slowly from 2010 to 2016, and fluctuated around 2017. In 2016, the changes between regions had become more evident. The provinces have begun to pay attention to the ecological environment and put forward a series of supportive policies to encourage the development of a green economy, encourage the level of green economy and spread to the surrounding areas, promote the green development of backward areas, and achieve cross-regional joint, green development.

According to Figure 3, the following characteristics can be summarized: the mean Gini coefficient between east-central and east-western regions is significant, at 0.178 and 0.15, respectively, and the mean Gini coefficient between central-western regions is small, at 0.075. The difference change trend between the east, northeast and northeast regions is similar, showing a slow-growth trend, but the overall fluctuation range is small; the value is between 0. 01. The difference between the central and western regions showed a trend of increase and decrease.

It is verified that the eastern region attaches great importance to the coordinated development of the economy and ecology in recent years and can continuously optimize the industrial structure with the support of related policies so that the green economic development in the eastern region is superior to the central and west regions. Figure 4 shows the source of the overall difference in green economic development.

From the point of view of the contribution to the overall difference in developing the national green economy, the interregional differential contribution rate is the largest It was between 0.05 and 0.09, and the average contribution rate was 0.076. It shows that interregional differences have become the primary source of the overall difference in developing the national green economy. The average contribution rate change ranges between the intra-regional differential contribution rate is 0.019–0.034, and the average contribution rate is 0.027. Interregional differences

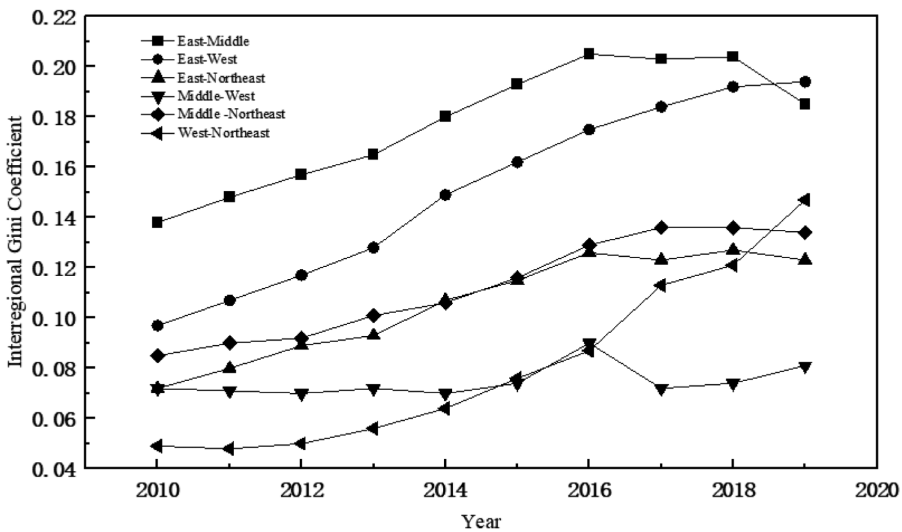


Figure 3. Regional differences in green economic development from 2010 to 2019.

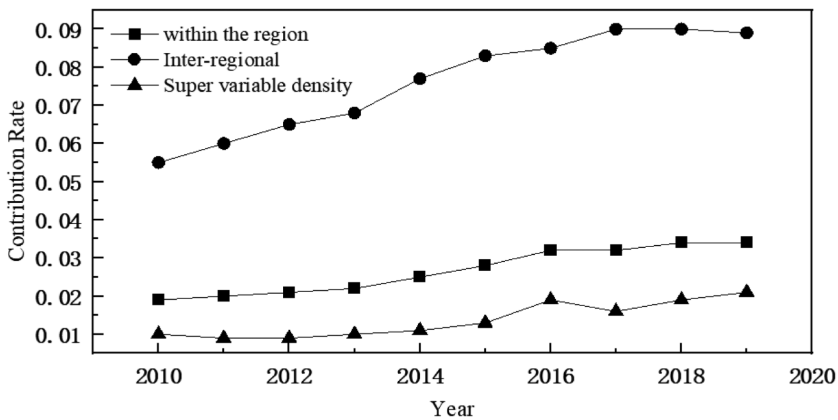


Figure 4. Contribution rate.

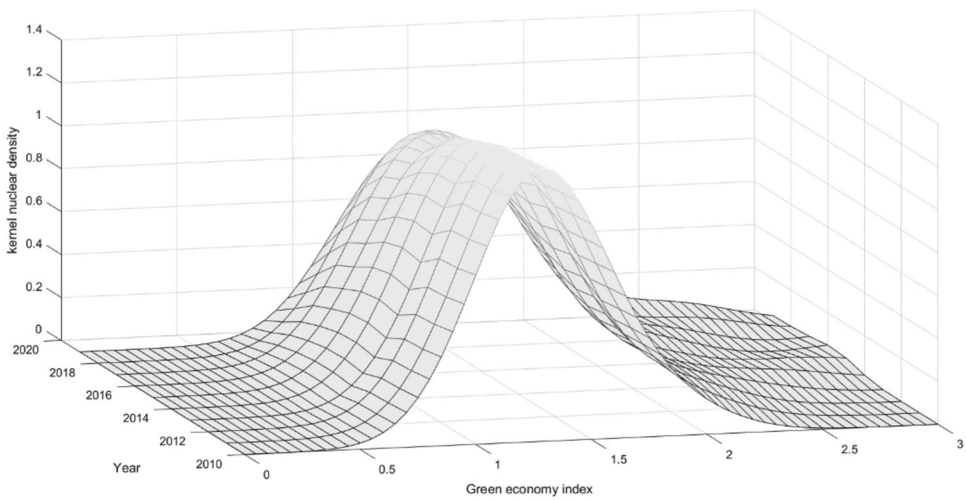


Figure 5. Distribution dynamics of national green economy development.

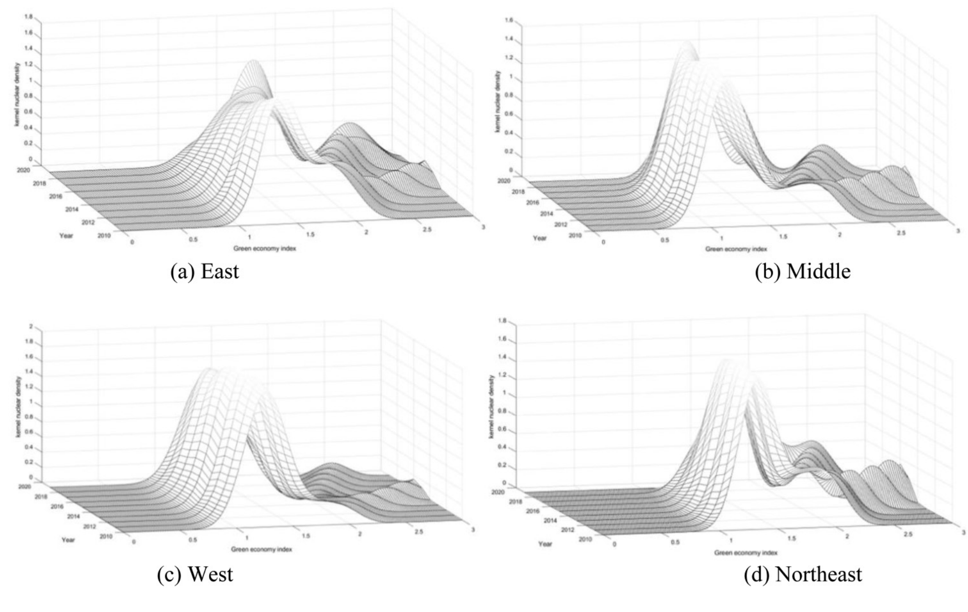
contribute less to the regional gap in green economic development than interregional differences. The contribution of super variable density between regions is between 0.009 and 0.021, with an average contribution of 0.014, indicating that the problem of overlapping samples between regions has a limited impact on regional differences in green economic development. Therefore, to solve the problem of regional differences in the development of the green economy, we should reduce the differences between regions further to narrow the green economy-level between the three regions and promote the coordinated development of all regions.

Distribution and dynamic evolution of green economic development. As shown in Figure 5, the overall trend is a right shift, and the height of the central peak is constantly rising. The distribution curve is always covered with right trailing and ductility widening, with only one central peak and no regional polarization. It is consistent with the previous analysis of the Gini coefficient, which shows that the green economic development level in the central and western regions is improving, and the absolute difference is narrowing.

According to Figure 6(a), the primary peak position of the level distribution curve of the green economic development in the eastern region is generally a moderate economic trend from 2012 to 2018, indicating that there is a polarization of green economic development in the eastern region. Green economic development in some provinces is in the primary position. According to Figure 6(b) and(c), the central and western regions green economy's development level distribution curve on the right, the main peak height overall trend, 2018–2019 region, the main peak width and the right drag tail without significant change, only one main peak, there is no regional polarization, that the green economy development level overall increases and show the trend of absolute difference.

According to Figure 6(d), the overall distribution curve of the green economy development level in the northeast region is an apparent move to the right. The height of the central peak is also constantly improving. From 2018 to 2019, the main peak height reached the highest point, and the flexibility of the right tail widened. There is always a central peak, and there is no regional polarization phenomenon.

Spatial correlation test Global autocorrelation analysis. The Moran I indices of the four matrices are all positive and pass the significance test of 1%. It shows a positive spatial correlation in China's green economy development. Developing a green economy in this province has a positive spatial spillover effect on the surrounding provinces, specifically manifested as the aggregation of high-level provinces. The spatial dependence is relatively stable. Therefore, from a general point of view, the spatial correlation is significant, and it is appropriate to choose a spatial econometric model (Table 3).



(a) East (b) Middle

(c) West (d) Northeast

Figure 6. Distribution dynamics of green economy development in the four regions. (a) graphical results for the East region of China. (b) graphical results for the Middle region of China. (c) graphical results for the West region of China. (d) graphical results for the Northeast region of China.

Further examining the spatial relevance of specific regions, taking the nested matrix as an example, a local Moran map of China's green economic development index was drawn. It should be noted that limited to space, only the results of 2010 and 2019 were reported, of which the numbers 1 to 30 represented 30 provincial-level regions in China: Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang.

As can be seen from Figure 7, the points corresponding to the Moran index of green economic development among provinces are primarily distributed in the first and third quadrants; each province has a robust positive promotion effect on local space, which is the same as the test results of the global Moran index.

From 2010 to 2019, most provinces in the first and third quadrant increased, reflecting the increased correlation of the level of green economy development in local regions, thus indicating that the local spatial positive correlation of individual provinces was significant. Therefore, the influence of spatial factors should be considered, and the spatial measurement model should be analyzed.

Selection of the spatial measurement model. For the best regression results, a series of tests are required to determine the specific form of the spatial panel model before performing model analysis. Follow these steps to select a spatial panel model.

The first step is to perform an LM inspection. Four spatial weights matrices are used to test the SEM and SAR models. Spatial correlation testing is performed on standard static panel regression (OLS), including LM-Lag and robust LM-Lag tests and LM-Error and robust LM-Error tests. If the LM test passes one or both of the models, the choice of spatial model is determined using the Wald test, or the spatial Dubin model is chosen if both null hypotheses are rejected.

Table 4 shows that under the spatial weights in 4, LM_test_Error and robust LM_test_Error pass the 1% significance test, while LM_test_Lag and robust LM_test_Lag pass the 10% significance test under the nested matrix, and the spatial Dubin model should be considered when accepting both the SEM model and the SLM model.

The second step is to test the effect of the choice. According to the panel model effects, they are divided into fixed and random effects, so we need to use the Hausman test To avoid the degradation

Table 3. The Global Moran's I Index for green economic development.

	W1		W2		W3		W4	
Year	Moran's I	Z	Moran's I	Z	Moran's I	Z	Moran's I	Z
2010	0.366***	3.832	0.349***	4.172	0.289***	2.716	0.061***	2.722
2011	0.407***	4.289	0.398***	4.772	0.287***	2.735	0.070***	3.036
2012	0.439***	4.629	0.436***	5.224	0.292***	2.794	0.075***	3.188
2013	0.439***	4.703	0.430***	5.241	0.282***	2.755	0.081***	3.409
2014	0.447***	4.918	0.444***	5.557	0.289***	2.899	0.082***	3.545
2015	0.447***	4.999	0.445***	5.653	0.288***	2.931	0.083***	3.637
2016	0.415***	4.696	0.416***	5.349	0.247***	2.578	0.069***	3.207
2017	0.440***	5.005	0.425***	5.509	0.295***	3.045	0.093***	4.001
2018	0.448***	5.087	0.439***	5.681	0.278***	2.896	0.087***	3.822
2019	0.393***	4.491	0.368***	4.806	0.336***	3.414	0.104***	4.326

Note: The authors calculated using Stata15; *** is significant at the 1% significance level.

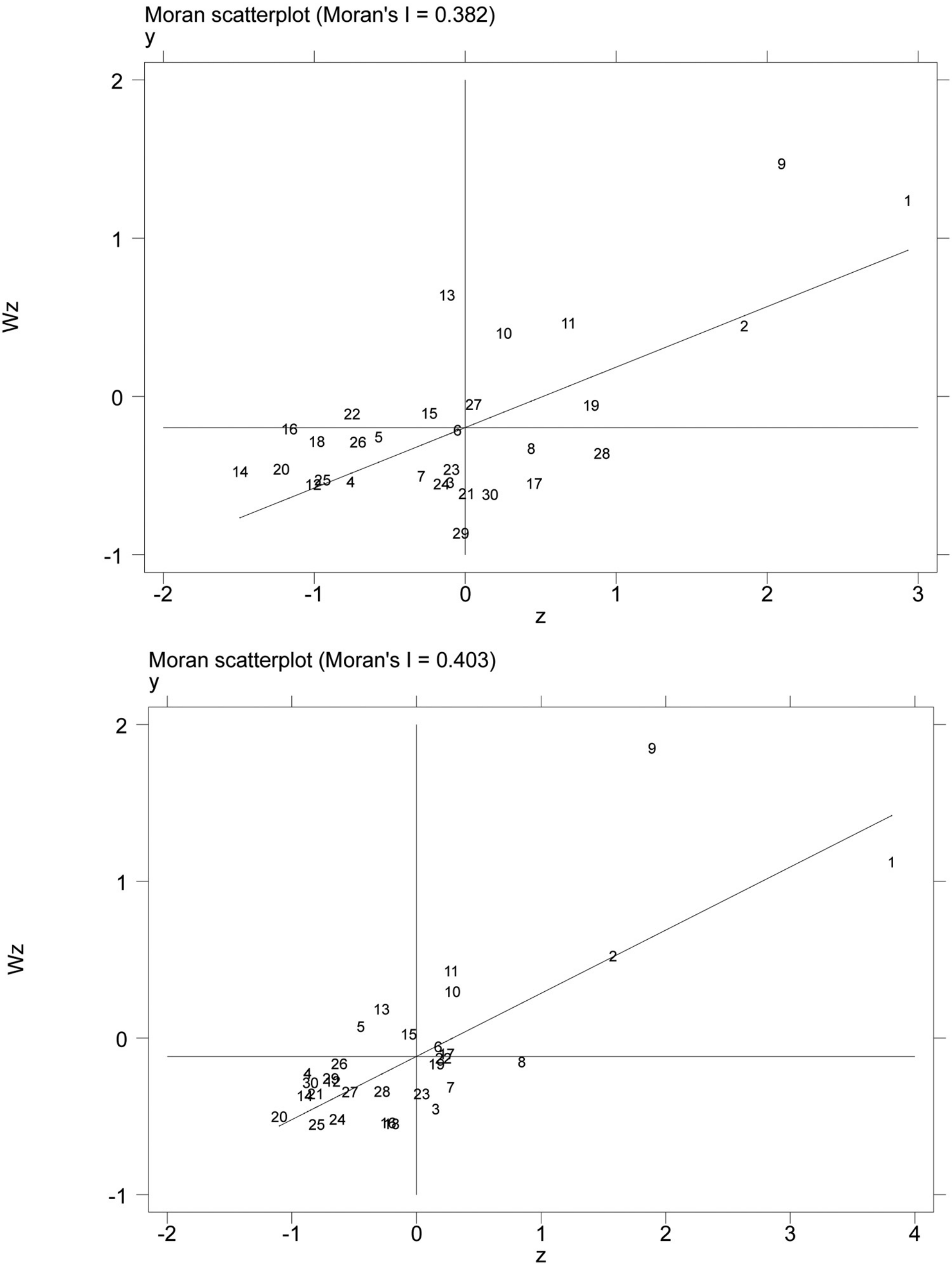


Figure 7. Local Moran Map of China's green economy development Index in 2010 and 2019.

of the SD model into a spatial lag model or a spatial error model, it is first assumed that the SD model can degenerate into a spatial lag model or a spatial error model. The two degradation model hypotheses are tested by the likelihood ratio test (LR test), and the test results are as follows (Table 5).

Table 4. The findings of the spatial dependence test.

	W1		W2		W3		W4	
	Statistic	*p* Value	Statistic	*p* Value	Statistic	*p* Value	Statistic	*p* Value
LM_test_Error	13.474	0.000	12.496	0.000	13.474	0.000	13.762	0.000
robust LM_test_Error	15.450	0.000	10.709	0.001	15.450	0.000	14.380	0.000
LM_test_Lag	0.070	0.012	2.274	0.132	0.070	0.792	0.841	0.359
robust LM_test_Lag	2.046	0.153	0.487	0.485	2.143	0.253	1.459	0.227

The four spatial weight matrices results strongly reject the null hypothesis, and the fixed effect model should be used. Therefore, it is reasonable to choose this paper's SD double fixed-effect model.

According to the regression results (Table 6), the goodness of fit of the SDM model was 0.8607. It was the best in each model. The LogL value was higher than that of other models. The significance of each variable coefficient was high, indicating that the SDM model estimation for the spatial analysis of green economic development is reasonable. The findings showed that Er, Gov, Ind and Edu have the significant role in providing green economic development. The estimated value of Er, Gov, Ind and Edu were 0.0648, 0.00154, 0.0035 and 0.118 (significant at 5% and 1%), respectively. Besides, the coefficients of W*Er, W*Gov, W*Ind and W*Edu were 0.0850, 0.0105, 0.0267 and 0.200, respectively. It means that Er, Gov, Ind and Edu stimulate the green economic development in the analysed regions. However, urbanization and openness of economy had the negative value (−0.0170 and −0.000478, respectively). It confirmed that urbanization and openness of economy restrict the green economic development. In addition, the coefficient of W*Urb was −0.111 which proved that urbanization in the analysed region did not stimulate the green economic development in adjacent regions. The coefficient of W*Open was 0.00355. It confirmed that Open stimulate the green economic development in adjacent regions. Thus, the Chinese government should increase the openness of economy and direct investment in improving the urbanization considering the principals of green economy (develop the green infrastructure, improve environmental regulation, spread the concept of green cities, and etc.).

Spatial Durbin model decomposition. Since the SD model explains the spatial economic correlation between provinces, the parameter estimation results cannot directly reflect the direct and real effects of the spatial spillover effect. The coefficients of influence of the respective variables on rural consumption are decomposed into direct effects, indirect effects and total effects about the partial differential method.[66, 67]

In analyzing the spillover effect of green economic development, the decomposing of the spatial effect into direct and spillover effects were applied, and the results are shown in Table 7. From the

Table 5. Hausman test and LR tests.

	W1		W2		W3		W4	
Test	Statistic	P-value	Statistic	P-value	Statistic	P-value	Statistic	P-value
Hausman test	Prob > chi2	0.000	Prob > chi2	0.000	Prob > chi2	0.000	Prob > chi2	0.000
LR test	Prob > chi2	0.000	Prob > chi2	0.000	Prob > chi2	0.000	Prob > chi2	0.000

Table 6. Results of the model regression.

Variable	SAR	SEM	SDM
Er	0.0562**	0.0602*	0.0648**
	(2.65)	(1.78)	(2.41)
Gov	0.00860**	0.00887***	0.00154**
	(2.54)	(2.69)	(2.57)
Ind	−0.00490*	−0.00389	0.0035**
	(1.82)	(−1.41)	(1.56)
Urb	−0.0394***	−0.0479***	−0.0170***
	(−6.60)	(−8.73)	(−3.34)
Open	0.000362**	0.00195*	−0.000478
	(2.28)	(1.76)	(−0.42)
Edu	0.192**	−0.214**	0.118**
	(2.74)	(−3.20)	(1.96)
W*Er			0.0850**
			(2.32)
W*Gov			0.0105
			(1.25)
W*Ind			0.0267***
			(4.52)
W*Urb			−0.111***
			(−8.64)
W*Open			0.00355*
			(1.69)
W*Edu			0.200**
			(2.32)
R-squared	0.6715	0.6530	0.8607
Log-L	287.3229	289.0481	364.8839
Observations	300	300	300

Note: *, **, *** have passed the significance test of 10%, 5%, and 1%.

perspective of direct effects, the regression coefficients of environmental regulation, government financial investment, industrial structure, level of opening up, and level of education development are all positive. They pass the significance test, indicating that they play a role in promoting the development of a green economy, which is consistent with the previous assumptions. From the perspective of the degree of role, education development has contributed the most, which further shows that as long as education is vigorously developed, outstanding talents are cultivated, scientific and technological progress is promoted, and sustainable development of the green economy is achieved. From the perspective of indirect effects, the regression coefficients of the industrial structure are all positive and pass the significance test at the level of 1%. The adjustment of the industrial structure can promote the region's development and play a significant role in promoting the development of neighbouring areas. The regression coefficients of the direct and indirect effects of the urbanization level are negative and significant, indicating that urbanization will inhibit the development of the green economy to a certain extent, which is consistent with the previous assumption.

Robustness test The nested spatial weights matrix is replaced by an adjacent spatial weight matrix, an economic distance spatial weights matrix, and a geospatial weight matrix. A double fixed effect SD model is used for regression analysis. The results show (Table 8) that the signs

Table 7. Spatial effect decomposition.

Variable	Direct effect	Indirect effect	Total effect
Er	0.0640**	0.0880**	0.151971*
Gov	0.0016	0.0104	0.012002
Ind	0.0038*	0.0278***	0.0316625***
Urb	−0.0172***	−0.1129***	−0.1300692***
Open	0.0005*	0.0036*	0.0040519*
Edu	0.1222*	0.1957	0.317828*

Note: *, **, *** have passed the significance test of 10%, 5%, and 1%.

of each explanatory variable were consistent with the fundamental regression, so the spatial spillover effects of the development of green economy efficiency were robust

The findings in Table 8 were the similar with findings of SDM model. Thus, Er, Gov, Ind and Edu had the statistically significant impact on green economic development. It indicates that ongoing policy on management of environmental development of the country was the priority direction and provoke the declining the environmental pollution. Besides, the modernization and optimization of the Chinese industry structure stimulate the further green economic progress. At the same time, Urb and Open were inhibitors of green economic development.

Discussion and conclusions

The integrated development tendency of the green economic development efficiency in the whole country was calculated using the super-efficient SBM model. The advantages and disadvantages of regional green economic development were analyzed from four central regions. Using the Dagum Gini coefficient and its decomposition method, regional difference and source of green economic development were clarified. Finally, the nuclear energy development, distribution dynamics, and absolute difference evolution between the four regions were shown using the nuclear density estimation method.

The spatial spillover effect of efficiency of green economic development was analyzed using a spatial metric model. The findings showed that the overall level of China's green economic development is not high, but the development efficiency index shows an upward trend year by year. In 2010, the green economy showed a high level of development. The efficiency of green economy development in other eastern regions was low, indicating that environmental protection was neglected to achieve rapid economic growth. There are more industrial enterprises in the central region, which affects the efficiency of green economic development; the economic development in the western region is slow, and the green economic development efficiency is at a medium level. In 2019, the efficiency of China's green economy development has been significantly improved, the number of provinces with high-level development has increased, and the number of provinces with low-level development has also been reduced, indicating that while achieving high-quality economic development, it also attaches importance to environmental protection. The similar conclusions were obtained by the study.[32, 68]

The results of the Dagum Gini coefficient show that the economic development of China's regional green economy is unbalanced. Furthermore, the findings allowed identifying the characteristics of the east-central-west-northeast ladder distribution. The regional differences are slight

Table 8. The regression results.

Variable	W2	W3	W4
Er	0.0591**	0.0431*	0.0578*
	(2.11)	(1.82)	(1.73)
Gov	0.000656	0.00636*	0.0124***
	(0.22)	(1.88)	(3.65)
Ind	0.00707**	−0.00557*	−0.00488
	(2.99)	(−2.16)	(−1.69)
Urb	−0.0307***	−0.0431***	−0.0336***
	(−6.09)	(−7.02)	(−5.48)
Open	0.000125**	0.000373*	0.00259*
	(2.1)	(1.72)	(1.98)
Edu	0.0576	−0.163*	−0.162*
	(0.97)	(−2.35)	(−2.34)
W*Er	0.0885*	−0.0583*	−0.258
	(1.74)	(−1.78)	(−1.15)
W*Gov	0.00613	0.00868	0.00602
	(0.70)	(1.30)	(0.31)
W*Ind	0.0321***	0.000461	0.0205
	(4.65)	(0.08)	(0.99)
W*Urb	−0.101***	0.0200	−0.0701
	(−7.26)	(1.84)	(−1.84)
W*Open	0.00715***	0.00167**	0.00308**
	(3.56)	(2.64)	(2.41)
W*Edu	0.220*	0.255*	0.600
	(1.66)	(2.18)	(1.38)
Individual fixed	YES	YES	YES
Time fixed	YES	YES	YES
Log-L	356.1676	304.4148	297.6487
R-squared	0.6617	0.6708	0.5974
Observations	300	300	300

Note: *, * *, * * * have passed the significance test of 10%, 5%, and 1%.

overall. The average contribution rate to regional differences is 0.027; the interregional differences are significant, and the average contribution rate to regional differences is 0.076, which has become the primary source of the overall differences in the development of the national green economy.

Green economy development uses the spatial correlation test method with a strong spatial correlation effect. The empirical findings complemented the conclusions of the papers.[69–72]. Further spatial models to obtain environmental regulation, government financial input, industrial structure, opening level, education level, and urbanization development suppress green economy development.

Theoretical and practical implication

In the theoretical framework the study contributed to development the approaches on analyses of green economic development efficiency. The study developed the following methods:super-efficient SBM model, distribution dynamics, nuclear density estimation method, spatial metric model.

Considering the findings, the following practical recommendations for policy implementations on China's green economic development could be suggested:

1. Update the fiscal and taxation considering the concept of green economic development. Thus, it is necessary to increase fiscal and taxation support of the green and energy-efficiency projects. The enlarging financial supporting allowed extending green environmental protection industry development projects, energy-efficient utilization, resource recycling, and etc.
2. Develop the relevant environmental regulation to reorient the agriculture, provide the obligatory green certification of the food. Thus, the western region should encourage the development of ecological planting and ecological breeding. It allows to increase the export Chinese agriculture product to the world food market.
3. Continue to provide the policy on the economy openness. Actively optimize the trade structure, vigorously develop high-quality, high-value-added green product trade, and strictly control the export of high-pollution and energy-consuming products. Strengthen international cooperation on green standards, deepen green "Belt and Road" cooperation, and broaden cooperation in technical equipment and services in energy conservation and environmental protection, clean energy, etc.
4. Develop the convergent policy of agriculture and tourism, education, culture, health, and other industries development. It allowed to synchronize the country's policies and promoting philosophy of green economy among society.
5. Provide the policy to enhance the urban green infrastructure and upgrading the waste management policy. Thus, it is necessary to promote the "integrated" management of urban domestic sewage collection and treatment facilities, accelerate the construction of harmless resource disposal facilities for sludge.

Author contributions

Conceptualization, Yang Chen, Farhan Ali, Oleksii Lyulyov, Tetyana Pimonenko; methodology, Yang Chen, Farhan Ali, Oleksii Lyulyov, Tetyana Pimonenko; formal analysis and investigation Yang Chen, Farhan Ali, Oleksii Lyulyov, Tetyana Pimonenko.; writing—original draft preparation, Yang Chen, Farhan Ali, Oleksii Lyulyov, Tetyana Pimonenko; writing – Yang Chen, Farhan Ali, Oleksii Lyulyov, Tetyana Pimonenko. All authors have read and agreed to the published version of the manuscript.

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