Pol. J. Environ. Stud. Vol. 30, No. 2 (2021), 1079-1093
DOI: *10.15244/pjoes/124758* ONLINE PUBLICATION DATE: 2020-11-06

Original Research

Spatial-Temporal Pattern and Influencing Factors of the Urban Green Development Efficiency in Jing-Jin-Ji Region of China

Herui Cui, Zilei Lui*

School of Economics and Management, North China Electric Power University,
#619 Yonghua Street, Baoding China

Received: 21 March 2020
Accepted: 28 June 2020

Abstract

As global problems such as the lack of resources and environmental degradation continue to intensify, the international community is increasingly aware of the importance of green development. At the same time, as a crucial guideline for China's ecological civilization construction, "Beautiful China" development, and global economic transition and restructure, green development will surely become the important engine for the green transformation and development of the Jing-Jin-Ji region and the whole country. Based on a thorough review of the concept of green development, this paper estimates the green development efficiency of 13 cities in Jing-Jin-Ji region of China in 2003-2017 by using the super efficiency SBM model. Then, by employing the coefficient of variation and the Global Moran's I, this paper further explores the spatio-temporal differentiation characteristics of the green development efficiency. Finally, the spatial panel model is used to explore the influencing factors of the green development efficiency. The results show the following: (1) The overall green development efficiency in Jing-Jin-Ji region of China declined steadily by 2% from 0.965 in 2003 to 0.948 in 2017. (2) The green development efficiency basically presents the spatial differentiation characteristics of the higher in the northern cities and the lower in the southern cities. (3) The green development efficiency has significant regional differences, and increased by 22% from 0.240 in 2003 to 0.295 in 2017. (4) Economic development level influence on the green development efficiency presents a "U" shaped curve that suppresses and then promotes. Industrial structure and the degree of openness have a positive influence, and urbanization have a negative influence on green development efficiency. Whereas, technological innovation has non-significant influence. Based on these findings, this paper proposes some targeted policy suggestions for promoting the green development efficiency.

Keywords: green development efficiency, super efficiency SBM model, spatial-temporal pattern, spatial econometrics method, Jing-Jin-Ji region

*e-mail: 1440063641@qq.com

Introduction

China, which has undergone the reform and opening up, has made remarkable achievements in economic development and has become the second largest economy in the world. However, while China has achieved economic growth, it is also facing difficulties such as environmental pollution and resource shortage. In the 2018 Global Environmental Performance Index Report, environmental performance in China ranked 120^{th} among 180 participating countries, with a relatively low position of 0.67. According to the calculation of the Chinese Academy of Sciences, the economic losses due to environmental pollution and ecological damage have accounted for 15% of China's GDP each year. The problem of high energy consumption, high emissions, and high pollution brought about by rapid economic growth is becoming increasingly serious, which has become a major factor restricting sustainable economic growth [1]. Facing the severe situation of resources and environment, the traditional socio-economic development model is in urgent need of transformation and upgrading.

China has been concerned about constraints on environmental capacity and has tried to improve its traditional economic model. Today, China realizes that the solution is the green urban development [2]. In order to actively promote green urban development, the Chinese government has proposed a green development plan to promote awareness of environmental protection and efficiency of resource utilization [3]. In particular, Green development has become a strategic choice for development of China since entering the 13^{th} Five-Year Plan. Green development is a concrete and effective way to achieve sustainable development [4-8], which means to respect, conform to and protect nature, and guide the socioeconomic transformation from an "industrial civilization" to an "ecological civilization" to achieve coordinated social and economic development along with ecological environmental protection [9].

Although the urban economy is growing in China, Chinese cities face a series of resource and environmental challenges, especially in Jing-Jin-Ji region [10]. At present, the internal development of the Jing-Jin-Ji region is extremely unbalanced, and the high concentration of population and highly polluting industries has exacerbated the scarcity of urban resources and environmental degradation [11]. In particular, environmental pollution problems such as haze weather that have occurred on a large scale in recent years have caused the contradiction between ecological environment and economic society to become extremely acute. Eco-environmental issues have become a major " short board " for urban development of the Jing-Jin-Ji region, and traditional resource-driven development model has become unsustainable. Therefore, the only way to realize the sustainable development of the Jing-Jin-Ji region is to implement the concept of green development and improve the urban green development efficiency.

Research on green development began as early as the 1960s. Boulding proposed the green development concept for the first time in the "Steady-state Economy". Pearce et al. emphasized the core of green development as a means to protect the environment. Sauri-pujol defined green development as environmental protection and economic growth [12]. With the in-depth understanding of the relationship between economic activities and resources and environment, especially after the 2008 international financial crisis, green development has become a topic of concern for international research institutions [13]. In 2011, the Organization for Economic Cooperation and Development considered green development as the solution to seek economic growth and development, as well as the key to prevent environmental degradation, biodiversity loss and unsustainable use of natural resources. In 2012, the UN Conference on Sustainable Development, which is also named as the Rio+20 conference, took "developing green economy" as the theme, clearly guiding the new development direction of "global economic transition to green", and further building consensus on green development. Subsequently, the concept of green development, that is, while maintaining economic growth, improving the utilization of resources and energy, avoiding excessive damage to the environment and excessive consumption of resources, has gradually become the common recognition of international academia in the new era.

The concept of green development fits well with the construction of beautiful China and the transformation and reconstruction of the global economy. Domestic and foreign scholars have conducted extensive and in-depth research on green development. Through the demonstration and research on the concept and connotation, measurement and evaluation indexes, strategic countermeasures and restrictive factors of green development, the thought of green development has formed a relatively systematic theoretical system. The key to green development is to improve the green development efficiency. Green development efficiency refers to the efficiency measurement that takes into account the increase in output and the reduction of pollutants, even including the reduction of resource input, while taking into account factors such as resource conservation, pollution control, and economic growth. Improving the efficiency of green development is an important way to realize ecological civilization construction and economic transformation. In other words, while achieving economic growth, it can also respond to resource conservation and environmental pollution reduction, and promote the shift to a green production and living development mode featuring low input, low emission and high yield [14]. Scholars mainly focus on the measurement and evaluation of green development efficiency, spatial and temporal differentiation, convergence and influencing factors. Embodied in, based on the DEA model and comprehensive evaluation index system to measure green development efficiency [15-23]. And then using the Malmquist index decomposition, thayer index and exploratory spatial data analysis and other methods to analyze its space-time evolution law. Finally, Tobit regression model and spatial panel model are constructed to focus on the influence of economic development level, industrial structure and environmental regulation on the green development efficiency [24-30]. These empirical studies systematically explored green development models and regional differences.

Summary of existing research findings: firstly, in terms of research content, it mainly focuses on the efficiency of a certain field or a specific meaning, such as economic efficiency, ecological efficiency, industrial efficiency and so on. The research on the urban green development efficiency in the complex "economy-society-nature" coupling system is not thorough and systematic enough. As the spatial carrier of green development, city is a coupling system of interaction among subsystems of nature, economy and society. Studying the urban green development efficiency and determining the effective allocation of input resources can objectively reflect the coordinated development degree of subsystems such as economy, society and nature. Secondly, in terms of the evaluation system, the index evaluation system of green development efficiency is not perfect. In terms of input indicators, the existing literature fails to fully consider the impact of technological input on production; the resource element input is only replaced by fossil energy consumption, and the impact of water, soil, energy consumption and other resource element input on production is not fully considered. In terms of output indicators, scholars have considered environmental pollution factors too much, while ignoring the social and ecological benefits of environmental improvement. Thirdly, in terms of the research scale, most of the existing studies analyze the green development efficiency from the macro scale of the whole country, province or specific region, but the detailed description of the urban scale within the region is insufficient, which cannot clearly reflect the spatial heterogeneity and correlation characteristics of the urban level within the region. Under the background of frequent flow of multiple factors, continuous diffusion of environmental pollution and interdisciplinary integration, it is necessary to study the urban green development efficiency by integrating the disciplines of economics and geography under the guidance of the three-circle system theory.

Based on this, starting from the city scale, this paper takes 13 cities in Jing-Jin-Ji region of China as the main research objects, systematically combing the concept and connotation of green development and efficiency, and on this basis, construct the urban green development efficiency of input-output evaluation system, then use the super-efficient SBM model to measure the green development efficiency of Jing-Jin-Ji region from 2003 to 2017, and use the coefficient of variation and the global Moran index to explore the spatial and temporal differentiation characteristics of green development efficiency. Finally, the spatial panel model is used to make an empirical analysis of the factors influencing green development efficiency, hoping to provide a certain decision reference for the green coordinated development of the three systems of economic, social and environmental in the Jing-Jin-Ji region.

Connotation and Theoretical Basis

The goal of green development is to enhance economic vitality, improve social welfare and increase resource wealth. It emphasizes the symbiosis of economic system, social system and natural system and the diversification of development goals, namely the integrity and coordination of the three systems [31]. According to the literature review, the current definition of green development is relatively vague, which leads to the unreasonable construction of the evaluation system of green development, and it is difficult to systematically and completely reflect the comprehensive evaluation of green development under the background of ecological civilization construction. Therefore, based on previous studies, this paper attempts to sort out and define the theoretical framework of the concept of green development (Fig. 1). The theoretical framework is an interactive system composed of internal and external circles: first, the external circles are composed of economic system, social system and natural system. In the economic system, green development is supported by the development elements of the new economic system, which are composed of industrial agglomeration, production optimization, scientific and technological innovation and economic globalization. The social system includes development concepts under the guidance of new eras and new ideas such as smart cities, social welfare, and financial support. The natural system is based on the five elements of "water, soil, gas, production and land", and the mutual coupling of these elements forms the green development benchmark of the natural circle. Secondly, the internal circles takes green welfare as the goal, green wealth as the basis, and green growth as the means, forming an internal circle composed of "green growth – green welfare – green wealth". These three connotations in the internal circles form a coupling symbiosis, which together embody the core requirements of green development. Therefore, green development is a sustainable development concept, which should take green growth, green welfare and green wealth as its connotation, integrate the three systems of economy, society and nature, and take development capacity, people's well-being and living environment as its basis [32].

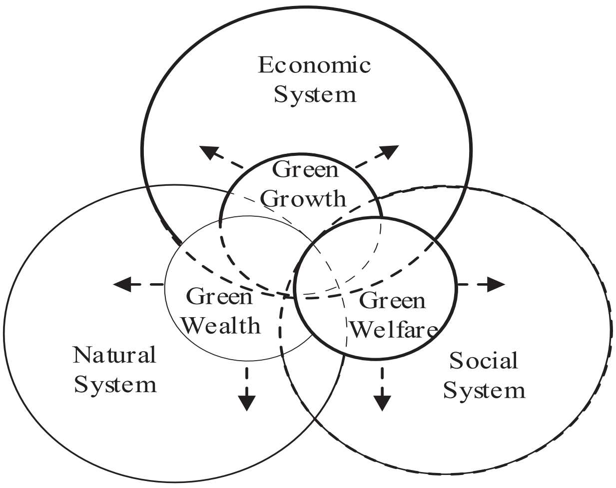

Fig. 1. Three-circle model for green development.

On the basis of clarifying the interaction of economy, society and natural system of the green development, this paper uses the "three circle model" to analyze the mechanism of urban green development. In this model, the economic system, social system and natural system take green growth, green welfare and green wealth as their main development directions respectively. Among them, the economic system is based on green growth and is influenced by green wealth and green welfare; the natural system is based on green wealth and is influenced by green growth and green welfare; the social system is based on green welfare and is influenced by green growth and green wealth (Fig. 1). To be specific, first of all, green growth is a means to accumulate green wealth and promote green welfare. Green growth can promote the accumulation of green wealth and the promotion of green welfare, reduce the conflicts between current and future generations in resource consumption, and realize the sustainability of green welfare. Secondly, green wealth is the carrier of green welfare and the basis of green growth, and the accumulation of green wealth is the long-term result of green growth. The accumulation of green wealth will help reduce the depletion of natural resources, improve the ecological environment and enhance human society's ability to adapt to climate change. Finally, green welfare is the goal of green growth, and is based on green wealth, and has a positive impact on green wealth and green growth. The promotion of green welfare involves not only the welfare of current generations, but also the welfare of future generations. In a word, the coupling relationship of green growth, green wealth and green welfare constitutes the internal mechanism of green development efficiency, and the effect of the internal mechanism is the green development efficiency. Based on the above concept connotation and theoretical basis, this paper carries out research.

Research Methods and Data Description

Research Methods

Firstly, data envelopment analysis (DEA) is one of the most commonly used measurement methods in existing researches on green development efficiency [33]. However, the traditional DEA model ignores the relaxation, which will lead to the deviation of measurement results [34,35]. Therefore, on this basis, Tone proposed an SBM model considering relaxation variables [36]. However, the efficiency measurement results of the traditional SBM model will have multiple effective decision making units with an efficiency value of 1. In order to solve the problem of effective decision making unit ordering [37], Tone further proposed the super efficiency SBM model [38]. Therefore, this paper adopts the super efficiency SBM model to calculate the urban green development efficiency in Jing-Jin-Ji region. The model is as follows:

$$\rho^* = \min \frac{\frac{1}{m}\sum_{i=1}^{m}\frac{\overline{x}}{x_{ik}}}{\frac{1}{(s_1+s_2)}\left(\sum_{p=1}^{s_1}\frac{\overline{y^d}}{y^d_{pk}}+\sum_{q=1}^{s_2}\frac{\overline{y^u}}{y^u_{qk}}\right)}$$

$$s.t.\begin{cases}\overline{x} \geq \sum\limits_{j=1,\neq k}^{n} x_{ij}\lambda_j; \overline{y^d} \leq \sum\limits_{j=1,\neq k}^{n} y^d_{pj}\lambda_j; \overline{y^u} \geq \sum\limits_{j=1,\neq k}^{n} y^d_{qj}\lambda_j; \overline{x} \geq x_k; \\ \overline{y^d} \leq y^d_k; \overline{y^u} \geq y^u_k \\ \lambda_j \geq 0, i=1,2,\ldots,m; j=1,2,\ldots,n; j \neq 0; p=1,2,\ldots,s_1; \\ q=1,2,\ldots,s_2 \end{cases} \tag{1}$$

...where, λ is the weight vector and $0<\rho^*<1$ is the target efficiency value. When the objective function $0<\rho^*<1$, the production decision unit is relatively ineffective. When $\rho^*\geq 1$, it means that the production decision unit is located on the optimal production front, and the larger ρ^* is, the higher the unit efficiency is.

Secondly, the coefficient of variation method (C.V) is widely used in the analysis of the degree of regional differences. Therefore, in this paper, the coefficient of variation method (C.V) is used to measure the regional differences in the green development efficiency in Jing-Jin-Ji region. The formula is as follows:

$$C.\mathrm{V} = \frac{1}{\overline{y}}\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(y_i-\overline{y}\right)^2} \tag{2}$$

...where: $C.V$ is the coefficient of variation method; $\overline{y}$ is the mean value of the urban green development efficiency in the region; y_i is the urban green development efficiency in the region, n is the number of cities in the region.

Thirdly, the Moran's I is one of the most commonly used methods for measuring spatial autocorrelation

[39,40]. This paper uses the Global Moran's I to test whether there is spatial autocorrelation in the global perspective. The formula of the Global Moran's I is expressed as follows:

$$I = \frac{1}{s^2} \cdot \frac{\sum_{i,j=1}^{n} W_{ij}\left(x_i - \overline{x}\right)\left(x_j - \overline{x}\right)}{\sum_{i,j=1}^{n} W_{ij}} \quad (4)$$

...where, $s^2 = \frac{\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2}{n}$ is the sample variance and $\sum_{i,j=1}^{n} W_{ij}$ is the sum of all space weights. Moran's I value ranges from –1 to 1. Where, $0<I<1$ indicates that there is a positive spatial autocorrelation between space units; $I = 0$ indicates that there is no spatial autocorrelation between space units; $–1<I<0$ indicates that there is a negative spatial autocorrelation between space units.

Finally, based on the traditional econometrics, spatial econometrics takes the "first law of geography" as its basis, and fully considers the spatial dependence and spatial heterogeneity between observation units. At this stage, spatial econometrics has developed into a more robust spatial econometric model framework. This paper mainly uses the following two spatial panel models: Spatial Auto Regression Model (SAR) and Spatial Error Model (SEM).

Spatial Auto Regression:

$$Y_{it} = \rho \sum_{j=1}^{N} w_{it} Y_{it} + \beta X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$
$$\varepsilon_{it} : \; N\left(0, \delta^2\right) \quad (4)$$

...where, Y_{it} is the explained variable, X_{it} is the explanatory variable, and β is the regression coefficient. $W = (W_{ij})$ is the spatial weighting matrix. μ_i represents spatial fixed effect; $W = (w_{ij})$ is for time fixed effect. ε_{it} is the random error Spatial Error Model:

$$Y_{it} = \beta X_{it} + \mu_i + \lambda_t + \varphi_{it}$$
$$\varphi_{it} = \sigma \sum_{j=1}^{N} w_{it} \varphi_{it} + \varepsilon_{it}$$
$$\varepsilon_{it} : \; N\left(0, \delta^2\right) \quad (5)$$

...where, φ_{it} is the random disturbance term, and σ is the spatial correlation coefficient of the random disturbance term. The rest of the parameters have the same meaning as the spatial auto regression model.

Variable Indicators and Data Sources

In view of the lack of data in cities below the prefecture-level cities in Hebei Province at the present stage, this paper adopts the "2 + 11" model generally accepted by most scholars. That is, two municipalities of Beijing and Tianjin, and eleven prefecture-level cities in Hebei Province were taken as the research objects.

Based on the "three-circle system theory" of green development mentioned above, and based on the input-output model, the input-output index system of the urban green development efficiency in Jing-Jin-Ji region of China was established (Table 1). Capital, labor, technology, resources and other factors are selected in terms of input. Specifically, the capital stock is selected to represent capital input, the number of employees at the end of the year is selected to represent labor input, the financial expenditure on science and technology and education is selected to represent technical input, and the resource input is expressed by the total consumption of water, soil and energy. In terms of expected output, the GDP of each region is selected to reflect the economic benefit, the social benefit index comprehensively reflects the social output, and the environmental benefit index reflects the output with a "good" environment. In addition, considering the value loss caused by waste emissions to the ecological environment in the development process, environmental pollution index is included in the evaluation system as a non-expected output factor, and resource and environmental constraints are considered as an important factor in the evaluation of the green development efficiency. The Entropy method is used to comprehensively calculate the resource factors, social benefit index, environmental benefit index and environmental pollution of each city. The GDP is adjusted to the constant price in 2000 based on the province 's GDP deflator. Since the capital stock cannot be directly obtained, the total capital investment in the whole society is used to represent the capital stock. The statistical data comes from "China City Statistical Yearbook (2004-2018)".

Result Analysis

Time-Evolution Characteristics

As shown in Fig. 2, from the overall trend, the green development efficiency in Jing-Jin-Ji region showed a steady decline from 2003 to 2017. The average value of green development efficiency dropped from 0.965 in 2003 to 0.948 in 2017, a decrease of 2%. The green development efficiency exhibits three-stage evolution characteristics: fluctuation decline period, fluctuation rise period and stable period. In the first stage, from 2003 to 2010, the urban green development efficiency presents a fluctuating and declining trend, from 0.965 in 2003 to 0.913 in 2010, a decrease of 5%. This stage was in the 10th Five-Year Plan and the 11th Five-Year Plan. China's economy was in a stage of rapid growth, with the rapid development of energy-intensive industries (including steel, petrochemical, power, etc.) and the rapid increase in energy consumption. In this stage, the

Table 1. Evaluation System of the GDE in Jing-Jin-Ji region.

Type	Level one	Level two	Level three
Inputs	Capital elements	Fixed capital stock	Total investment in fixed assets of the whole society
	Labor elements	Number of employees	Number of employees at the end of the year
	Technical elements	Expenditure on science, technology and education	Financial Expenditure of Science, Technology and Education
	Resource elements	Total consumption of water, soil and energy	Total water supply, area of urban built-up area, electricity consumption of the whole society, artificial and natural gas supply, liquefied gas supply
Outputs	Desirable outputs	Economic benefits	GDP (constant price in 2000)
		Social benefit	Average wages of urban employees, total retail sales of consumer goods
		Environmental benefits	Urban green space area, green space coverage rate, comprehensive utilization rate of industrial solid waste, centralized treatment rate of sewage treatment plants, harmless treatment rate of domestic garbage
	Undesirable outputs	Environmental pollution	Industrial wastewater discharge, industrial SO^2 discharge, industrial soot discharge

economic development model ignores environmental factors to some extent, thus the ecological environment suffers great damage and environmental pollution is prominent. Therefore, the overall green development efficiency shows a declining trend. In the second stage, from 2011 to 2013, the urban green development efficiency was in the stage of improvement, increasing from 0.923 in 2011 to 0.993 in 2013, an increase of 7%, which is a big change. This stage was in the 12th Five-Year Plan. The government has strictly implemented the targets of "energy conservation and emission reduction". Through strict implementation of environmental protection measures and intensified efforts to adjust the industrial structure, the problems of high energy consumption and high pollution have been effectively controlled. In the third stage, from 2014 to 2017, the urban green development efficiency presents a trend of stable fluctuation, from 0.954 in 2014 to 0.948 in 2017, a decrease of 0.6%. Although preliminary achievements have been made in urban environmental governance during the development process, the coordination between economic growth and ecological environment in Jing-Jin-Ji region has not reached the optimal state due to the slowdown of GDP growth, so the urban green development efficiency has entered a stable period. Thus it can be seen that the green development efficiency in Jing-Jin-Ji region presents an obvious phased feature in time series.

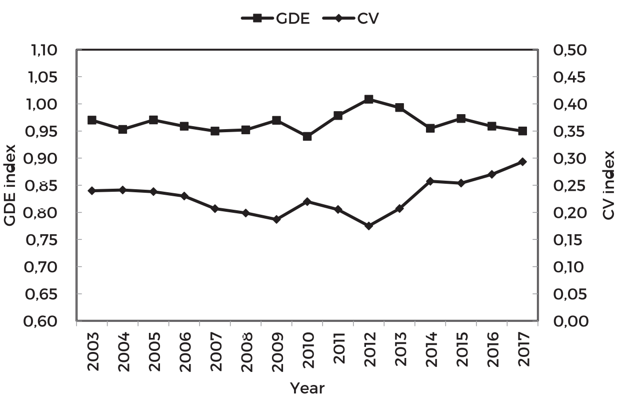

Fig. 2. Trend of GDE in Jing-Jin-Ji region from 2003 to 2017.

As shown in Table 2, from the perspective of the city, from 2003 to 2017, the efficiency values of the four cities, including Beijing, Tianjin, Hengshui, and Langfang, showed an overall upward trend. The efficiency values of two cities, including Tangshan and Shijiazhuang, were flat, indicating that the inputs and outputs in the green development process of these cities are relatively commensurate. Hengshui, Chengde, Zhangjiakou, Qinhuangdao and other cities have higher green development efficiency, which is closely related to their lower economic development starting point and less development burden, so they can adapt to the requirements of green development in a timely manner. However, Beijing, Tianjin and other cities rely on the advantages of relatively advanced technology and industrial agglomeration, and their green development efficiency is ahead of other cities. In addition, the overall green development efficiency of seven cities including Handan, Xingtai, Baoding, Zhangjiakou, Qinhuangdao, Cangzhou, and Chengde has generally declined, which may be caused by irrational industrial structure and extensive economic growth model.

Spatial Differentiation Characteristics

In this paper, Geoda software was used to calculate the Moran's I (as shown in Table 3) of the green development efficiency in Jing-Jin-Ji region from 2003 to 2017, taking geographical distance as the spatial weight matrix. This indicates that there is a significant

Table 2. The GDE of the Jing-Jin-Ji region from 2003 to 2017.

Cities	2003	2005	2007	2009	2011	2013	2015	2017
Beijing	1.190	1.253	1.206	1.248	1.326	1.371	1.475	1.465
Tianjin	1.054	1.045	1.060	1.086	1.112	1.126	1.119	1.117
Shijiazhuang	0.619	0.713	0.741	0.741	0.741	1.020	0.687	0.649
Tangshan	1.065	1.040	1.013	1.002	1.011	1.006	1.083	1.034
Qinhuangdao	1.207	1.182	1.207	1.140	1.158	1.042	1.023	1.036
Handan	0.642	0.621	0.752	0.744	0.744	0.702	0.668	0.470
Xingtai	0.607	0.608	0.608	0.672	0.659	0.594	0.601	0.598
Baoding	0.738	0.702	0.712	0.771	0.810	0.759	0.696	0.672
Zhangjiakou	1.052	1.042	1.026	1.005	1.005	1.026	1.026	0.892
Chengde	1.261	1.261	1.047	1.039	1.134	1.127	1.111	1.064
Cangzhou	1.052	1.107	1.106	1.147	1.100	1.080	1.048	1.053
Langfang	1.057	1.059	0.838	1.004	0.838	0.944	1.122	1.106
Hengshui	1.004	1.033	1.031	1.044	1.082	1.114	1.118	1.165

spatial correlation and dependence of the green development efficiency among Jing-Jin-Ji region as a whole. In addition, from the time series point of view, the Moran's I fluctuated from 2003 to 2014, and increased after 2015. This can be considered as the continuous improvement of the Jing-Jin-Ji regional development policy in the early stage. With the implementation of the Jing-Jin-Ji coordinated development strategy and the strengthening of regional division of labor and cooperation, the spatial agglomeration characteristics of the urban green development efficiency have become increasingly prominent.

In order to further explore the spatial differentiation characteristics of the green development efficiency in Jing-Jin-Ji region, this paper selects three time nodes in 2003, 2010 and 2017, and uses ArcGIS software to draw the quantile map of the urban green development efficiency. Based on the practice of previous scholars, this paper divides the green development efficiency into four types: high efficiency, medium-high efficiency, medium efficiency and low efficiency. That is, the green development efficiency value is greater than 1.200 belongs to the high efficiency area, the efficiency value between 1.000-1.200 is the medium-high efficiency area, the efficiency value between 0.700-1.000 is the medium efficiency area, and the efficiency value lower than 0.700 belongs to the low efficiency area. The darker the color, the higher the green development efficiency.

As can be seen from Fig. 3, the green development efficiency in Jing-Jin-Ji region presents the spatial differentiation characteristics of the higher in the northern cities and the lower in the southern cities on the whole. The high efficiency areas are located in the northern part of the Jing-Jin-Ji region: Zhangjiakou-Chengde-Qinhuangdao; The two core cities in Jing-Jin-Ji region are Beijing and Tianjin; Eastern coastal area of the Jing-Jin-Ji region: Qinhuangdao-Tangshan-Cangzhou. The low efficiency areas are located in the central and southern areas of Jing-Jin-Ji region: Baoding-Handan-Xingtai. And the space scope of the medium efficiency area is not fixed. However, it is worth noting that from 2003 to 2010, Langfang transferred from high efficiency area to medium efficiency area. However, by virtue of its superior location between the two core cities of Beijing and Tianjin, Langfang has finally realized the transformation from a medium efficiency area to a high efficiency area from 2011 to 2017 by establishing a leading

Table 3. Global Moran's I of GDE in Jing-Jin-Ji region from 2003 to 2017.

Index	2003	2004	2005	2006	2007	2008	2009	2010
Moran's I	0.261	0.251	0.243	0.229	0.120	0.090	0.200	0.117
P-values	0.000	0.000	0.000	0.000	0.005	0.016	0.000	0.006
Index	2011	2012	2013	2014	2015	2016	2017	
Moran's I	0.100	0.155	0.096	0.132	0.205	0.240	0.192	
P-values	0.010	0.000	0.008	0.002	0.000	0.000	0.000	

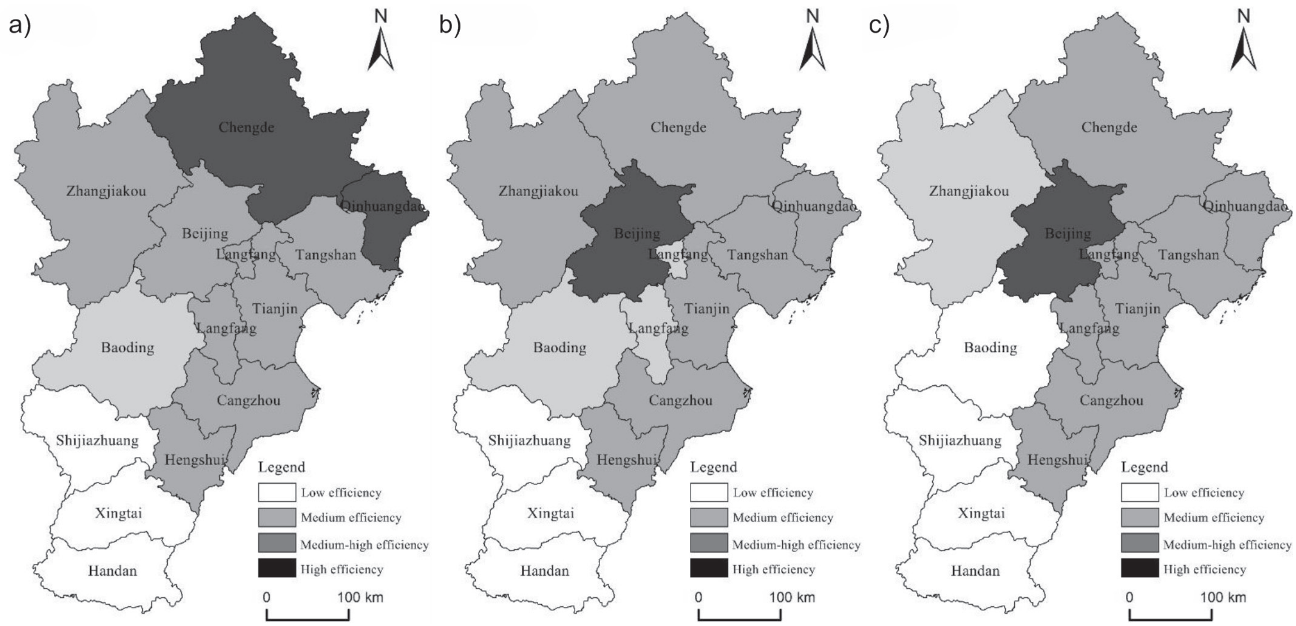

Fig. 3. The Spatial Distribution of GDE in Jing-Jin-Ji region in years a) 2003, b) 2010, c) 2017.

region for the transformation of scientific research and innovation achievements and implementing the strategy of industrial structure transformation and upgrading. On the contrary, in 2010, Zhangjiakou and Baoding respectively changed from high efficiency area to medium efficiency area and from medium efficiency area to low efficiency area. Therefore, it is necessary to pay attention to the old road of „resources and environment for growth, pollution first and treatment later,, represented by Zhangjiakou and Baoding. This also demonstrates the urgency and importance of China's initiative in 2017 to build the Xiongan New Area and Zhangbei Area into two wings of Hebei and promote the coordinated development of the Jing-Jin-Ji region in accordance with the requirements for high-quality development. The low efficiency area is mainly located in the central and southern parts of the Jing-Jin-Ji region. In particular, the green development efficiency of resource-based cities such as Handan and Xingtai has been maintained at a low level, while Shijiazhuang, as the provincial capital, has not played a leading role in improving the green development efficiency of this region. Therefore, the region needs to build a new urban development pattern to improve its overall level of green development.

Difference Characteristics

As shown in Fig. 2, the regional differences in the green development efficiency in Jing-Jin-Ji region are relatively obvious. From 2003 to 2017, the coefficient of variation (C.V) index was V- shape, showing an overall expansion trend. From 2003 to 2009, as the urban green development efficiency fluctuated and declined, regional differences gradually narrowed. The C.V index decreased from 0.240 in 2003 to 0.187 in 2009, a decrease of 22%. From 2010 to 2014, regional comprehensive differences showed an upward trend, increasing from 0.220 in 2010 to 0.257 in 2014, an increase of 17%, and regional differences have expanded significantly. From 2015 to 2017, the regional differences in the green development efficiency in Jing-Jin-Ji region further expanded. It increased from 0.254 in 2015 to 0.295 in 2017, an increase of 16%. It can be seen that the polarization of the green development efficiency among Jing-Jin-Ji region is still severe.

From the perspective of the city, this paper draws on the research methods of Teng et al. to compare and analyze the green development efficiency with the level of urban economic development based on per capita GDP [42], so that the Jing-Jin-Ji region are divided into four categories: high economic development level-high green development efficiency level; high economic development level-low green development efficiency level; low economic development level-high green development efficiency level; low economic development level-low green development efficiency level. The three time nodes of 2003, 2010 and 2017 are selected, and the classification results of the types of the green development efficiency in each city are shown in Fig. 4.

In 2003, Beijing and Qinhuangdao belonged to high-high type cities, and seven cities including Tianjin, Tangshan, Cangzhou, Langfang, Chengde, Zhangjiakou and Hengshui belonged to low-high type cities. Baoding, Handan, Xingtai. In 2010, Tianjin, Tangshan, and Cangzhou entered the ranks of high-high type; Qinhuangdao changed from high-high type to low-high type, with per capita GDP growing slowly, but its green development efficiency remained at the forefront of production; and Langfang turned from

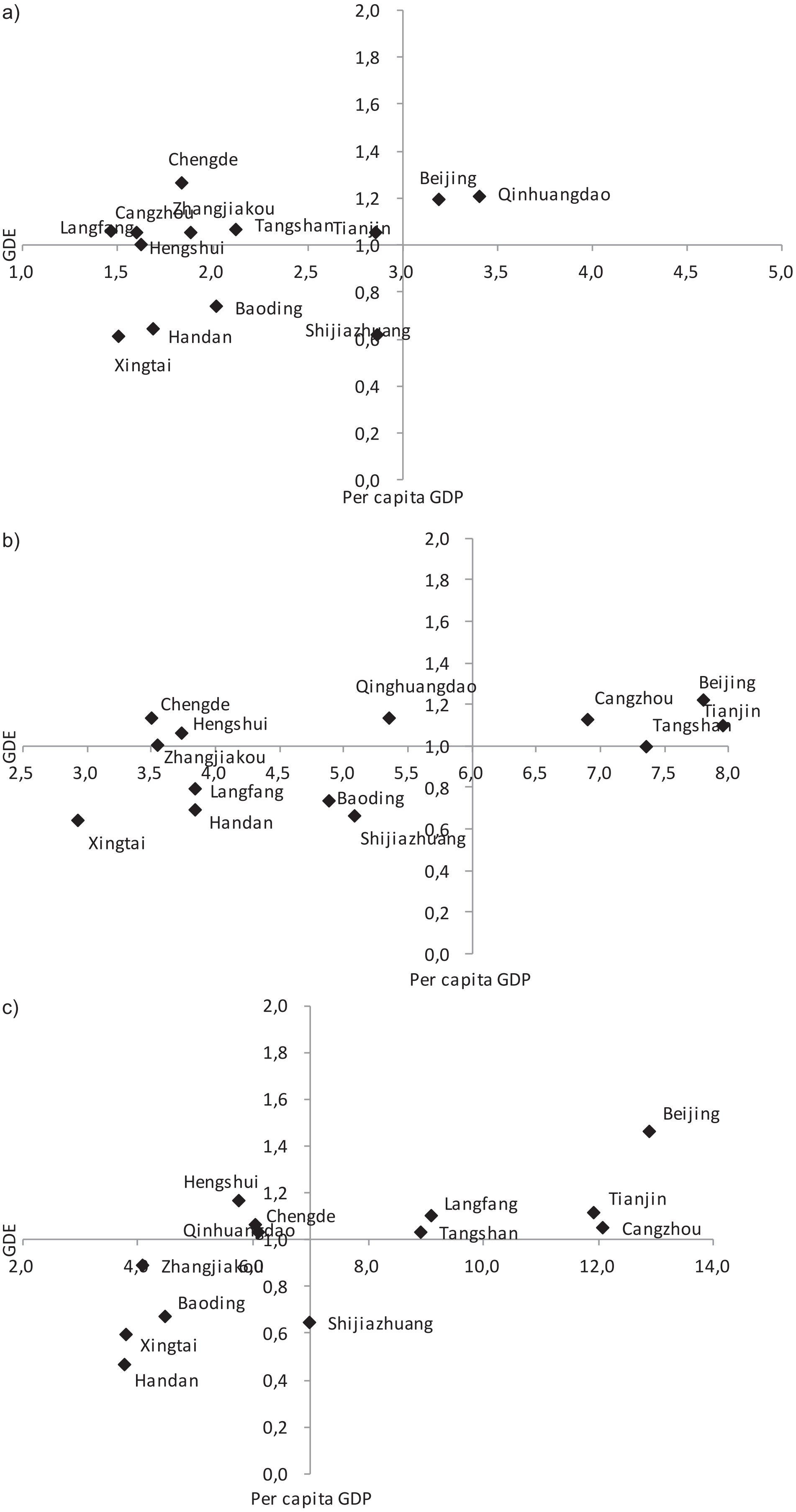

Fig. 4. Type of GDE in Jing-Jin-Ji region fin years a) 2003, b) 2010, c) 2017.
Note: In the figure, the abscissa is per capita GDP/10,000 yuan, and the ordinate is the value of the green development efficiency.

low-high type to low-low type. In 2017, Langfang entered from the low-low type into the high-high type. At the same time that the per capita GDP has increased significantly, the green development efficiency has also picked up. On the contrary, Zhangjiakou has changed from a low-high type to a low-low type city; Note that Shijiazhuang, Tangshan and other cities have a tendency to switch to high-low type cities.

In general, high-high type cities, such as Beijing and Tianjin, are at a relatively high level of economic development, and they have a high level of science and technology and a positive sense of environmental protection, making them capable and conscious of both economic development and ecological environment protection, thereby improving the green development efficiency and excellent input-output structure. Low-high type cities, such as Qinhuangdao, Chengde, and Hengshui, can be roughly divided into three categories. The first is that cities with low economic development starting points and small development burdens, such as Hengshui and Zhangjiakou, can obtain relatively more output; second, tourist cities, such as Qinhuangdao and Chengde, special industrial structures make these cities consciously control the degree of environmental pollution, so their green development efficiency can be maintained at a high level; third, ecological regional cities, such as Chengde, Zhangjiakou, as important water conservation areas and windbreak and sand fixation areas in Jing-Jin-Ji region, are important supports for the ecological environment of Jing-Jin-Ji region and have a good green foundation. Therefore, although its economic development level is relatively backward, it still remains at the forefront of production. Besides, it is worth noting that cities near the high-low type, such as Shijiazhuang, Tangshan, and other cities with large economic volumes. Firstly, as a provincial capital, the advantages of Shijiazhuang in infrastructure investment make its investment structure unreasonable. At the same time, it faces difficulties such as backward technological level and insufficient innovation ability, so its input-output efficiency is low. Secondly, cities like Tangshan are still in the development stage dominated by industry. There are a large number of industries with heavy pollution, such as steel and cement. Despite the high level of economic development, Tangshan still faces serious ecological and environmental problems. The low-low cities are mainly economically underdeveloped cities located in the central and southern part of Jing-Jin-Ji region, such as Baoding, Handan, and Xingtai. At present, the economic development level of these cities is relatively low, with extensive industries such as heavy industry and traditional industries. In particular, resource-based cities such as Handan and Xingtai, which are dominated by industries of high energy consumption and high pollution, have produced a large number of unexpected output, and have a long way to go to achieve green development.

Analysis of Influencing Factors

Variable Selection

Considering the availability of data, this study focuses on exploring the influencing factors that lead to the evolution of the spatial and temporal pattern of green development efficiency in Chinese cities from the perspective of humanities and social development, and verifies the "Porter Hypothesis" and "Pollution Paradise Hypothesis" of green development efficiency in Chinese cities. This paper uses the logarithm of GDP per capita (rgdp) to measure the level of economic development, and the regression coefficient is expected to be positive. Green development is the main policy and strategy of China's ecological civilization construction in the new era, which lays more emphasis on the coordinated development of the environmental system and the economic and social system. Through the regulation of the ecological environment, the efficiency of resource allocation can be improved and the degree of economic and social development can be enhanced. Therefore, in the process of development, it is worth thinking about economic growth and technological innovation. The quadratic relationship between green development efficiency and per capita GDP was verified by logarithmic per capita GDP squared ($rgdp^2$). According to the "Porter Hypothesis" theory, strict environmental protection policies will not only lead to increased costs, but may promote technological innovation so that they can gain a comparative advantage in new competition and promote their own development. Therefore, the proportion of the sum of science expenditure and education expenditure in the local fiscal expenditure is used to reflect technological innovation (te) and to test whether there is a "Porter hypothesis" in the implementation of green development policies. The process of economic globalization has a significant impact on the growth of urban industries. Through the use of foreign direct investment, industries participate in economic globalization, strengthen their own comparative advantages, absorb advanced science and technology and management experience, and actively acquire knowledge spillover and innovative activities to promote industrial growth. But at the same time, industries with a high proportion of foreign capital are usually technology- intensive or capital-intensive industries, with a large total output value and a relatively low growth rate. In addition, foreign capital may also have a competitive squeeze effect, thereby affecting industrial growth and not conducive to the improvement of urban green development efficiency. The proportion of the actual use of foreign capital in the total social fixed asset investment (fdi) is used to represent the degree of openness of each city, so as to test the existence of the "pollutant shelter effect" and "pollutant paradise" hypothesis, and the expected coefficient is uncertain. At the same time, this paper selects the urban industrial structure (ind) and the proportion of the added

Table 4. The result of the LM test.

Tests	Statistics	P-values
LM(lag)	21.479	0.000
Robust LM(lag)	7.313	0.007
LM(error)	14.213	0.000
Robust LM(error)	0.047	0.000

value of urban tertiary industry in GDP to measure the rationalization and upgrading degree of urban industrial structure, and the regression coefficient is expected to be positive. In addition, existing studies on the impact of urbanization on the green development efficiency mainly focus on population urbanization and land urbanization. It is believed that population urbanization is conducive to the agglomeration of labor force and high-end factors of production and can promote green development. However, land urbanization focuses on the expansion of city scale and strengthens the factor driving tendency of economic growth, which leads to the distortion of resource allocation and further hinders green development. The Jing-Jin-Ji region is a strategic region. In order to ensure steady economic development, the local government may have a tendency of land urbanization. The ratio of urban permanent residents to the total population is used to represent the level of urbanization (urban), and the expected coefficient is uncertain.

Estimation Results

Firstly, the measurement result of Moran's I shows that the urban green development efficiency in Jing-Jin-Ji region has a spatial correlation, so it is reasonable to use a spatial econometric model to analyze the influencing factors of the urban green development efficiency.

Secondly, the least squares estimation is performed on the ordinary panel model without spatial factors, and then the LM test and Robust LM test are used to test the spatial correlation of the lag terms and residuals, so as to choose the form of spatial model [42]. It can be seen from Table 4 that both the LM (lag) test and Robust LM (lag) test are significant at the 1% level, but Robust LM (error) fails the 10% significance level test. Therefore, spatial autoregressive model (SAR) is selected for empirical analysis.

Finally, the statistical value of the Hausman test is 59.37, which corresponds to a significant P-value of 1%, indicating that the fixed effect is better than the random effect. In addition, the fixed effect model is divided into three forms: time fixed effect, spatial fixed effect , and double fixed effect. Therefore, in this paper, under the three fixed effect models, a spatial lag model is used for estimation in order to choose the most suitable model. The results of tests are shown in Table 5.

By comparing the values of R^2 and $Log - L$, it is found that the interpretation effect of the time fixed effect model of spatial autoregression is the most reasonable compared with the other two models.

Analysis of Estimated Results

(1) There is a U-shaped relationship between the level of economic development and the green development efficiency. The $Lnrgdp^2$ coefficient is significantly positive and the Lnrgdp coefficient is significantly negative. With the development of the economy, the urban green development efficiency has shown a trend of first decline and then increase. In the

Table 5. Results of estimation and test of SAR model.

Variables	Time fixed effect	Spatial-fixed effect	Double fixed effect
Rgdp	-1.677**	-1.048**	-0.587*
rgdp 2	0.063**	0.035**	0.021**
Ind	0.121**	0.054*	0.041
aggl2	-0.247***	-0.025***	-0.041***
aggl3	0.169***	0.073***	0.083***
Fdi	0.003	0.008	0.005
Tie	0.279**	0.261***	0.331***
Gov	-0.075**	0.011*	-0.038
Urban	-0.152*	-0.029	-0.075*
ρ	0.595***	0.181**	0.017*
R^2	0.392	0.276	0.147
Log-L	256.001	146.386	147.260

Note: *** represents a significant level of 1%, ** represents a significant level of 5%, and * represents a significant level of 10%.

early stage of economic development, that is, urban development is in the stage of extensive economic growth, the urban green development efficiency will gradually decrease; and when economic development reaches a certain level, that is, urban development is in the stage of high-quality development, the urban green development efficiency will gradually increase. (2) The industrial structure has a significant positive impact on the green development efficiency and has passed the 99% significance level test, showing that the Jing-Jin-Ji city cluster can effectively improve the urban green development efficiency by actively developing the tertiary industry, effectively controlling the scale of the secondary industry and promoting the transformation and upgrading of the industrial structure in a reasonable and orderly manner during the transformation and upgrading of the industrial structure. (3) Opening to the outside world significantly promotes green development efficiency, and has passed the significance test at the level of 1%. It shows that since 2003, the Jing-Jin-Ji region has successfully passed the stage of "pollution refuge effect" and "pollution paradise" that are common in developing countries. With the continuous deepening of the scientific development concept and the concept of sustainable development, China has made various considerations on foreign investment, so that it must meet not only the needs of economic development but also the requirements of ecological civilization construction and green development policies. (4) The coefficient of urbanization is negative and passed the significance test at the level of 10%, which shows that the urbanization model of most cities in Jing-Jin-Ji region still belongs to the land urbanization model. The extensive urbanization construction of each city has further eroded the green ecological space of the city, resulting in the decline of the green development efficiency. (5) Technological innovation has a positive impact, but the effect is not significant. Technological innovation can play an important role in solving ecological and environmental problems and maintaining productivity growth. The "Porter Hypothesis" advocates a proactive environmental protection policy, and believes that strict and appropriate environmental regulations can stimulate enterprises to carry out technological innovation, and their innovation benefits can offset or even exceed environmental protection costs, thereby enhancing the competitiveness of enterprises. From the perspective of the Jing-Jin-Ji region, the use of improving urban green development efficiency as a means of environmental regulation has not played a significant role in promoting technological innovation in various cities, and the "reverse mechanism" of technological innovation has not yet been formed. According to the Porter hypothesis, environmental regulation has a positive effect on enterprise technological innovation and even competitiveness, but this is conditional, that is, only when the economic level of a country or region develops to a certain degree, the situation may only appear as described in the "Porter hypothesis".

Conclusion and Policy Implications

Conclusion

(1) From 2003 to 2017, the urban green development efficiency in Jing-Jin-Ji region of China showed a steady decline, from 0.965 in 2003 to 0.948 in 2017, a decrease of 2%, but there were heterogeneities among cities. The urban green development efficiency in Jing-Jin-Ji region showed the characteristics of three stages: from 2003 to 2010, the urban green development efficiency fluctuated and declined; from 2011 to 2013, the urban green development efficiency was in the stage of improvement; from 2014 to 2017, the overall urban green development efficiency showed a trend of stable fluctuations. Specific to the interior of the urban agglomeration, the efficiency values of 4 cities including Beijing, Tianjin, Hengshui, and Langfang showed an overall upward trend from 2003 to 2017, and the efficiency values of 2 cities such as Tangshan and Shijiazhuang were flattened. The green development efficiency of Handan, Xingtai, Baoding, Zhangjiakou, Qinhuangdao, Cangzhou, Chengde and other seven cities declined.

(2) The urban green development efficiency in Jing-Jin-Ji region presents the spatial differentiation characteristics of the higher in the northern cities and the lower in the southern cities on the whole. The high efficiency areas are located in the northern part of the Jing-Jin-Ji region: Zhangjiakou-Chengde-Qinhuangdao; The two core cities in Jing-Jin-Ji region are Beijing and Tianjin; Eastern coastal area of the Jing-Jin-Ji region: Qinhuangdao-Tangshan-Cangzhou. The low efficiency areas are located in the central and southern areas of Jing-Jin-Ji region: Baoding-Handan-Xingtai. And the space scope of the medium efficiency area is not fixed.

(3) The urban green development efficiency in Jing-Jin-Ji region from 2003 to 2017 showed a trend of polarization, increasing from 0.2398 in 2003 to 0.2932 in 2017, an increase of 22%. The coefficient of variation (CV) index is in the form of "V". From 2003 to 2009, the coefficient of variation (CV) index fluctuated and the regional differences gradually narrowed. From 2010 to 2017, the Jing-Jin-Ji city coefficient of variation (CV) index increased rapidly, and regional differences continued to expand. At the same time, further analysis found that the combination of the green development efficiency and economic development level of the 13 cities in Jing-Jin-Ji region presents four types: high-high, high-low, low-high and low-low. Specifically, high-high cities: Beijing and Tianjin. On the verge of high-low cities: Shijiazhuang and Tangshan. Low-high cities: Qinhuangdao, Chengde, Hengshui, etc. Low-low cities: Baoding, Handan, Xingtai.

(4) There is a u-shaped relationship between green development efficiency and economic development level in Jing-Jin-Ji region. The industrial structure has a significant positive effect on the urban green development efficiency in Jing-Jin-Ji region. Opening to the outside world is significantly positively related

to the urban green development efficiency. The effect of foreign investment on pollution transfer is not obvious, but it will improve the quality of the environment. The effect of “pollutant refuge” is not established. Urbanization has a negative impact on the urban green development efficiency in Jing-Jin-Ji region. The land urbanization model in most cities in the Jing-Jin-Ji region has exacerbated the reliance on extensive economic development paths and inhibited the improvement of urban green development efficiency. The effect of technological innovation on improving the urban environment is not significant, and improving the environmental quality through technological innovation cannot be achieved in China at this stage.

Policy Implications

Based on the influencing factors in the empirical conclusions, we can also make some policy recommendations.

First, there is a “U” shaped relationship between the level of economic development and the green development efficiency, and most cities in Jing-Jin-Ji region are located at the left end of the “U” shaped curve. Cities such as Chengde, Zhangjiakou and Qinhuangdao in the northern part of the Jing-Jin-Ji region, as well as Baoding, Handan and Xingtai in the central and southern parts of the Jing-Jin-Ji region, are in a stage where the green development efficiency is decreasing with economic development. Therefore, these cities should be vigilant against the old path of “ecological environment in exchange for economic growth“. They should attach equal importance to economic development and ecological protection, promote the transformation of economy to green and intensive development, and fundamentally avoid and reverse the situation of declining in green development efficiency.

Second, the industrial structure is the key factors affecting the green development efficiency in Jing-Jin-Ji region. “Green“ is the basic orientation of urban industrial development in the northern region of the Jing-Jin-Ji region. To make full use of the ecological advantages and coastal resources advantages of Zhangjiakou, Chengde, and Qinhuangdao, a negative list of industrial access should be established, a “green +” development model should be implemented, and the development of green industries such as ice and snow sports, tourism and recreation, and green product supply should be focused. At the same time, we should build the Xiongan New Area into an “ engine “for the green development of the Jing-Jin-Ji region, and promote the diffusion of high-quality green industrial resources to the outside, forming a new pattern of urban industries featuring complementary functions and dislocation development of “Science and technology research and development in Beijing, industrial incubation in Xiongan New District, supporting layout of cities in Hebei Province, and export of Tianjin Port“, thereby solved the green development predicament of cities in the central and southern regions of the Jing-Jin-Ji region through industrial transformation and upgrading.

Third, we should expand the degree of openness and strengthen green supervision and screening of “quality” of foreign investment. In particular, the central and southern parts of the Jing-Jin-Ji region, including Shijiazhuang, Baoding, Handan, Xingtai and other cities, should implement the industrial access list system and prepare positive lists and negative lists to accurately control the flow of foreign capital into industries with high pollution and high energy consumption, and actively guide the flow of foreign capital to green and advanced industries, so as to avoid becoming a “pollution paradise”.

Fourth, technological innovation can effectively improve the green development efficiency. As the dual-core growth poles of the Jing-Jin-Ji region, Beijing and Tianjin need to change the development model that depends on the expansion of the urban scale and economic investment. They should increase investment in science and technology, upgrade green innovation technologies, and gradually upgrade industries with high pollution and high investment, and accelerate the upgrading of its own industry. At the same time, the urban green development resources of Beijing and Tianjin will also be transferred to other cities in Jing-Jin-Ji region during the process of optimal allocation. Especially at this stage, the relocation of non-capital functions will drive the flow of technology and talents as well as the transfer of science and education industries, and provide a solid technical and talent support for the industrial transformation and upgrading of the Jing-Jin-Ji region, especially the cities in the areas surrounding the capital.

Fifth, vigorously promote new-type urbanization and promote the transformation of urbanization pattern to intensive mode. We will strive to make Tangshan and Shijiazhuang the green growth poles of provincial cities, and strengthen the economic and population carrying capacity of major provincial cities such as Baoding and Handan. We will explore the green urbanization model of “ecological planning + comprehensive ecological environment management + industrial innovation”, strengthen the ecological conservation functions of Zhangjiakou, Chengde, and Qinhuangdao, and form a new pattern of the Jing-Jin-Ji regions with complementary functional advantages and coordinated green development.

Conflict of Interest

The authors declare no conflict of interest.

References

1. CHEN L.L., ZHANG X.D., HE F., YUAN R.S. Regional green development level and its spatial relationship under the constraints of haze in China. Journal of Cleaner Production, **210**, 376, **2019**.
2. JI Q.F., Li C.C., JONES P. New green theories of urban development in China. Sustainable Cities and Society, **30**, 248, **2017**.
3. XIAO M., LIN Y.L., HAN J., ZHANG G.Q. A review of green roof research and development in China. Renewable and Sustainable Energy Reviews, **40**, 633, **2014**.
4. LIN B., BENJAMIN N.I. Green development determinants in China: a non-radial quantile outlook. Journal of Cleaner Production, **162**, 764, **2017**.
5. WANG M.X., ZHAO H.H., CUI J.X., FAN D., LV B., WANG G., LI Z.H., ZHOU G.J. Evaluating green development level of nine cities within the Pearl River Delta, China. Journal of Cleaner Production, **174**, 315, **2018**.
6. BAGHERI M., GUEVARA Z., ALIKARAMI M., KENNEDY C.A., DOLUWEERA G. Green growth planning: a multi-factor energy input-output analysis of the Canadian economy. Energy Economics, **74**, 708, **2018**.
7. MATRAEVA L., SOLODUKHA P., EROKIN S., BABENKO M. Improvement of Russian energy efficiency strategy within the framework of "green economy" concept (based on the analysis of experience of foreign countries). Energy Policy, **125**, 478, **2019**.
8. YANG Y.Y., GUO H.X., CHEN L.F., LIU X., GU M.Y., KE X.L. Regional analysis of the green development level differences in Chinese mineral resource-based cities. Resources Policy, **61**, 261, **2019**.
9. ZHANG Y., SHEN L., SHUAI C., BIAN J., ZHU M., TAN Y., YE G. How is the environmental efficiency in the process of dramatic economic development in the Chinese cities? Ecological Indicators, **98**, 349, **2019**.
10. ZHANG J.X., CHANG Y., ZHANG L.X., LI D. Do technological innovations promote urban green development? – A spatial econometric analysis of 105 cities in China. Journal of Cleaner Production, **182**, 395, **2018**.
11. LI X. Scientific development and a new green deal. China Finance and Economic Review. **2** (1), 2, **2014**.
12. SAURI-PUJOL D. Environment and economy: property rights and public policy. Economic Geography, **68** (4), 4, **1992**.
13. SMIT S., MUSANGO J.K. Towards connecting green economy with informal economy in South Africa: A review and way forward. Ecological Economics, **116**, 154, **2015**.
14. CHE L., BAI Y.P., ZHOU L., JI X.P., QI F.W. Spatial pattern and spillover effects of green development efficiency in China. Scientia Geographica Sinica, **38** (11), 1788, **2018** [In Chinese].
15. WANG Y., LI H.Y., YU H. Analysis of spatial pattern and evolution characteristics of provincial green development in China. China Population, Resources and Environment, **28** (10), 96, **2018**.
16. SUN C., TONG Y., ZOU W. The evolution and a temporal-spatial difference analysis of green development in China. Sustainable Cities and Society, **41**, 52, **2018**.
17. TIAN J., ZANG N., XU Y., CHEN L. Green development index of the Chinese national economic-technology development area. Acta Ecologica Sinica, **38** (19), 7082, **2018**.
18. TAO X., WANG P., ZHU B. Provincial green economic efficiency of China: A non-separable input-output SBM approach. Applied Energy, **171**, 58, **2016**.
19. MA L., LONG H., CHEN K., TU S., ZHANG Y., LIAO L. Green growth efficiency of Chinese cities and its spatio-temporal pattern. Resources, Conservation and Recycling, **146**, 441, **2019**.
20. LIU X., GUAN K. Measurement and evaluation of the green development efficiency of the Yangtze River Economic Belt in Hubei province. Statistics & Decision, **34** (18), 103, **2018** [In Chinese].
21. ZHAO X., FU C., WANG G. Evaluation of the green development efficiency of yangtze river basin based on super efficiency DEA Malmquist index. Ecological Economy, **35** (8), 46, **2019** [In Chinese].
22. YUAN W.H., LI J.C., MENG L., QIN X.N., QI X.X. Measuring the area green efficiency and the influencing factors in urban agglomeration. Journal of Cleaner Production, **241**, 118092, **2019**.
23. SU S., ZHANG F. Modeling the role of environmental regulations in regional green economy efficiency of China: Empirical evidence from super efficiency DEA-Tobit model. Journal of Environmental Management, **261**, 110, **2020**.
24. BAN L., YUAN X. Differences and spatial influence mechanism of green economic efficiency between China's eight regions. Journal of Xi'an Jiaotong University(Social Sciences), **36** (3), 22, **2016** [In Chinese].
25. QIAN Z.M., LIU X. Regional differences in China's green economic efficiency and their determinants. China Population, Resources and Environment, **23** (7), 104, **2013** [In Chinese].
26. DONG X.J., SHI T. The green development efficiency and influencing factors of central plains urban agglomeration. German Economic Review, **5**, 116, **2018**.
27. LIN B., ZHU J. Fiscal spending and green economic growth: Evidence from China. Energy Economics, **83**, 264, **2019**.
28. CAO P., BAI Y.P. The temporal and spatial pattern of the green development efficiency in China and its influencing factors. Gansu Social Science, **4**, 242, **2018**.
29. FENG C., HUANG J.B., WANG M. Analysis of green total-factor productivity in China's regional metal industry: a meta-frontier approach. Resources Policy, **58**, 219, **2018**.
30. ZHANG H., XIONG L., LI L., ZHANG S. Political incentives, transformation efficiency and resource-exhausted cities. Journal of Cleaner Production, **196**, 1418, **2018**.
31. HU A.G., ZHOU S.J. Green development: Functional definition, mechanism analysis and development strategy. China Population, Resources and Environment, **24** (1), 14, **2014** [In Chinese].
32. ZHOU L., CHE L., ZHOU C.H. Spatio-temporal evolution and influencing factors of urban green development efficiency in China. Acta Geographica Sinica, **74** (10), 2027, **2019** [In Chinese].
33. ZHOU P., ANG B.W., POH K.L. Measuring environmental performance under different environmental DEA technologies. Energy Economics, **30** (1), 1, **2008**.
34. FUKUYAMA H., WEBER W.L. A directional slacks-based measure of technical inefficiency. Socio-Economic Planning Sciences, **43** (4), 274, **2009**.
35. SONG M., WANG S. Analysis of environmental regulation, technological progression and economic

growth from the perspective of statistical tests. Economic Research Journal, **3**, 122, **2013** [In Chinese].
36. TONE K. A slacks-based measure of efficiency in data envelopment analysis. European Journal of Operational Research, **130** (3), 498, **2001**.
37. SUEYOSHI T., YUAN Y. China's regional sustainability and diversified resource allocation: dea environmental assessment on economic development and air pollution. Energy Economics, **49** (8), 239, **2015**.
38. TONE K. A slacks-based measure of super-efficiency in data envelopment analysis. European Journal of Operational Research, **143** (1), 32, **2002**.
39. LI Y., LONG H., LIU Y. Spatio-temporal pattern of China's rural development: a rurality index perspective. Journal of Rural Studies, **38**, 12, **2015**.
40. TALEN E., ANSELIN L., LEE S., KOSCHINSKY J. Looking for logic: the zoning-land use mismatch. Landscape and Urban Plan, **152**, 27, **2016**.
41. TENG T., QU C., HU S., ZENG G. On the economic growth effect of the coordinated innovation of the Yangtze River Delta urban agglomeration under the integrated national strategy. Journal of East China Normal University(Humanities and Social Sciences), **51** (5), 107, **2019** [In Chinese].
42. ANSELIN L., BERA A.K., FLORAX R., YOON M.J. Simple diagnostic tests for spatial dependence. Regional Science ang Urban Economics, **26** (1), 77, **1996**.