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Spatial-temporal Characteristics of Green Development Efficiency and Influencing Factors in Restricted Development Zones: A Case Study of Jilin Province, China

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Abstract: Green development is an important issue of sustainable development in China. Due to the relatively backward economy and the fragile ecological environment, restricted development zones need to embrace green development. Taking 38 counties in Jilin Province as the empirical research objects, and based on cross-sectional data for each county in 2005, 2010, and 2015, we accurately depicted the spatiotemporal evolutionary characteristics of green development efficiency (GDE) in restricted development zones of Jilin Province using the slacks-based measure-data envelope analysis (SBM-DEA) model. Moreover, the factors that influence GDE were further analyzed using the Tobit model. We found that: first, GDE showed a V-shaped trend in restricted development zones of Jilin Province. The differences in GDE in the eastern, central, and western Jilin Province increased gradually. Second, 76% of counties in the restricted development zones had high or higher efficiencies. The resource-based cities were the main areas with low or lower GDE. Third, the economic development level was the core factor affecting GDE. Urbanization level had a significant negative effect on GDE in the restricted development zones. The effect of technological innovation level on GDE fluctuated, and we found that a 'backward mechanism' of technological innovation was beginning to form. Industrial structure and environmental governance had no significant effects on GDE.

Keywords: green development efficiency; spatiotemporal evolution; influencing factor; restricted development zones; Jilin Province

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1 Introduction

'Green development' is a new kind of sustainable development that operates under the constraints of resources and environment to promote economic development. The idea of green development can be traced back to 1989 when David Pierce first proposed the concept with environmental protection as its core component. Since then, many international organizations and researchers have studied green development from different perspectives. The United Nations Environment Programme (UNEP, 2011) released their report 'Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication', pointing out that green development is a low-carbon, green, energy-saving and environment-protecting economic growth model. Embracing the themes of poverty reduction, the green economy, and sustainable development, the United Na-

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tions Conference on Sustainable Development (Rio+20 Earth Summit) held in Rio Janeiro, Brazil, in 2012 proposed the promotion of green growth based on innovations in the economic paradigm, which is regarded as a new milestone in the concept of sustainable development. Green development can effectively break through resource and environmental constraints, solve ecological environmental problems in economy development process, and resolve the contradiction between economic development and the ecological environment (Macias-Fauria, 2018). Research on green development has focused mainly on the following three aspects: first, in the study of green development theory, Jänicke (2012) showed that green development was supported by environmental protection and resource- saving technologies and needed to maintain a moderate economic scale. Smulders et al. (2014) divided green development into ‘weak green development’ and ‘strong green development’. Jakob and Edenhofer (2014) discussed issues related to green growth, economic scale, and environmental investment. Second, in the study of green development level and efficiency evaluation, Kortelainen (2008) used data envelope analysis (DEA) to compare and analyze the environmental performance of 20 European Union (EU) member states between 1990 and 2003. Jarvis et al. (2011) established a statistical method of multiple indicators to predict and analyze the green employment potential of major developing countries. Chardine-Bauman and Botta-Genoulaz (2014) proposed a sustainability evaluation model to evaluate the economic, social, and environmental effects of the supply chain management system in order to improve its sustainable operation efficiency. Using the traditional DEA model and the non-expected output slacks-based model (SBM), Ren et al. (2017) objectively evaluated the economic and ecological efficiencies of the four major urban agglomerations in the eastern coastal region of China and analyzed the spatiotemporal evolution characteristics of the ecological efficiency of those urban agglomerations. Zhou et al. (2019) accurately depicted a full picture of China’s spatiotemporal patterns of urban green development efficiency (GDE) in 2005–2015 using the SBM-Undesirable and Spatial Markov Chain methods. Third, in the study of green development policy, Reilly (2012) used the general equilibrium model to establish the economic account of resources and environment and analyzed the growth potential of the green economy and the corresponding policies. McKendry and Janos (2015), taking Seattle and Chicago as examples, discussed the green growth and sustainable development of industrial cities in developed countries. Green development is a new proposition in China’s ‘New Era’. The positive research achievements of the past have laid a solid scientific foundation for in-depth research on green development. Scholars are using the DEA model, the total factor productivity model, and the direction and distance function model to evaluate GDE.

China made great progress in economic development following the reform and opening-up processes of the 1980s and 1990s, but it also accumulated some contradictions and problems. The most important of these were the disorder of spatial development, the low efficiency of the spatial allocation of elements and resources, and the conflict between humans and nature. In order to promote the effective protection and rational utilization of territorial space and realize the coordinated development of population, resources, and environment, Chinese geographers established the theory and practice of the Major Function Oriented Zone, a new method of spatial regulation for reshaping regional development patterns (Fan et al., 2012). Based on the resources and environment carrying capacity, the existing development strength, and the future development potential of a region, China’s land space was divided into four main functional types: optimized development zone, key development zone, restricted development zone, and forbidden development zone (Fan, 2013). According to the Major Function Oriented Zone, the category of restricted development zone is an important one for strengthening ecological restoration and protection, prohibiting large-scale industrialization and urbanization, and ensuring national (regional) ecological and agricultural product safety. Restricted development zones are the key areas of regional coordinated development and human land relationship system control in China. The best way to realize this kind of coordinated regional development needs careful consideration. Studies of restricted development zones by Chinese researchers focus mainly on functional segmentation (Zhong, 2011; Zhu et al., 2015; Mi et al., 2016), economic development evaluation (Guo et al., 2020), development mechanism and mode (Song et al., 2017), policy guidance (Chen, 2015; Yang et al., 2018). Existing researches tend to evaluate the economic development of restricted development zones from the perspective of development capacity (Li and Chen, 2011), economic development capacity (Guo et al., 2014), spatial differentiation (Mi et al., 2017; Guo et al., 2018), and coordination between the economic system and the ecological environment (Yu et al., 2016).

The main content of GDE is green growth, green science and technology, green energy, and green innovation. The GDP share of industries related to low energy consumption, adaptation to human health, and environmental friendliness is constantly rising so as to achieve low resource consumption and pollution emissions decoupled from economic growth (Tao et al., 2017). In general, most existing relevant studies take country, province, city clusters, prefectural city, and industry as the analysis objects, measure the GDE of cities, and analyze the temporal and spatial characteristics of GDE (Lu et al., 2016; Che et al., 2018; Liu et al., 2019; Zhou et al., 2019). However, there has been a lack of sufficient attention paid to the typical area of sharp conflicts between environmental protection and regional development—restricted development zones. A restricted development zone, as one of the four main types of functional areas in China, is a region with the control of development as its main function, bearing the national mission of 'restricted development' and the demand for and pressure of economic breakthrough development in underdeveloped areas (Fan, 2015). Because of the contradiction between economic development and ecological environmental protection in such areas, it is urgent that a green development model be established under the constraint of ecological environmental capacity and resource carrying capacity so as to adapt to the development requirements of restricted protective development of development zones. Improving GDE is an important way of realizing ecological civilization construction and economic transformation. Based on the above analysis, this study took restricted development zones in Jilin Province as the research objects. First, the SBM-DEA model was used to evaluate the GDE of Jilin Province restricted development zones, and the Tobit model was then used to explore the factors that affect GDE. This study is expected to enrich theoretical research on the coordinated development of the human–land relationship. In practice, it is hoped that it will help promote the green transformation of restricted development zones in Jilin Province and provide a reference for scientific development policies.

2 Materials and Methods

2.1 Study area and data sources

Jilin Province is an important grain commodity base and a key ecological functional area in China. According to the 'Plan for Development Priority Zones in Jilin Province', the restricted development zones there include 41 counties. Among them, 28 counties are major agricultural production areas, and 13 counties are key national ecological functional areas (Changbai mountain forest ecological functional area and Horqin grassland ecological functional area). The restricted development zones account for 86.43% of the total land area in Jilin Province (Statistic Bureau of Jilin, 2016). Although there are 41 counties in restricted development zones of Jilin Province, this study only included the GDE of 38 counties due to a lack of relevant statistical data for Shuangyang District, Jiutai District, and Dongchang District (Fig. 1). In order to study the regional spatial differences, this study divided the restricted development zones of Jilin Province into the eastern, central, and western Jilin Province. The eastern Jilin Province includes 15 counties under the jurisdiction of Tonghua City, Baishan City, and Yanbian Korean Autonomous Prefecture. The central Jilin Province includes 14 counties under the jurisdiction of Changchun City, Jilin City, Siping City, and Liaoyuan City. The western Jilin Province includes nine counties under the jurisdiction of Songyuan City and Baicheng City.

This study used cross-sectional data for the counties for 2005, 2010, and 2015. The data for construction land area were obtained from the Data Center of Resources and Environmental Sciences, Chinese Academy of Sciences, Beijing (http://www.resdc.cn/). Based on Landsat TM/ETM remote sensing images, the data were extracted from land use maps for 2005, 2010, and 2015 with an accuracy of 1 km × 1 km. The data for environmental impact come from the 'Environmental Statistics Bulletin' of each county for 2005, 2010, and 2015. Other basic data were obtained from the China statistical yearbook 'county-level' (Department of rural socio economic investigation, National Bureau of Statistics, 2006–2016) and the Jilin Statistical Yearbook (Statistic Bureau of Jilin, 2006–2016).

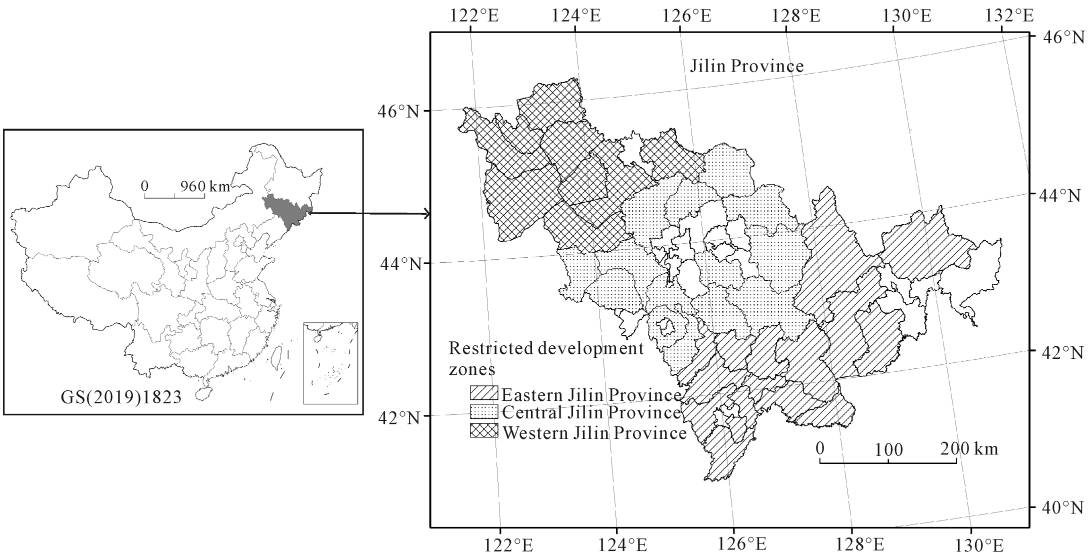

Fig. 1 Location of the study area in Jilin Province, China

2.2 Methods

2.2.1 SBM-DEA model and index system

GDE is an important index for evaluating the efficiency of economic operation under the constraints of resources and environment. GDE is more than traditional development efficiency and can reflect the efficiency of economic growth and environmental rationality. The analysis of efficiency problems usually begins from the perspective of input and output, and the main analysis methods include stochastic frontier analysis (SFA), data envelopment analysis (DEA), and total factor productivity model (Dyckhoff and Allen, 2001; Tone, 2001). Because the traditional radial DEA model fails to take into account the slack variable part of the invalid decision-making units (DMUs), there is a deviation in the efficiency measure with the non-expected output. In order to correct the relaxation variables, Tone and Sahoo (2004) proposed an Slack-based Model (SBM) model that considered the non-expected output and added environmental pollutants into the model as bad outputs. This model solves the problem of efficiency measurement of green economy operation under the constraint of resources and environment. In this paper, the SBM-DEA model considering non-expected output is used to calculate the GDE of restricted development zones in Jilin Province. Each county is a DMU, assume that the input vector $x \in R^m$, the expected output vector $y^g \in R^{s_1}$, and the non-expected output vector $y^b \in R^{S_2}$. Then, the input and output matrix of each DMU can be expressed as:

$$
\begin{aligned}
X &= (x_{i,j}) \in R^{m \times n} \\
Y^g &= (y_{i,j}) \in R^{S_1 \times n} \\
Y^b &= (y_{i,j}) \in R^{S_2 \times n}
\end{aligned} \tag{1}
$$

where n is the number of DMUs.

In the matrix: $X > 0, Y^g > 0, Y^b > 0$, and

$$P = \{(x, y^g, y^b) \big| x \geq X\lambda, y^g \leq Y^g\lambda, y^b \geq Y^b\lambda, \lambda \geq 0\} \tag{2}$$

where P is the production unit possibility set, λ is the intensity vector.

The SBM-DEA model dealing with undesirable outputs for evaluation DMU (x_0, y_0^g, y_0^b) is as follows:

$$\rho^* = \min \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{i0}}}{1 + \frac{1}{s_1 + s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{r0}^g} + \sum_{r=1}^{s_2}\frac{s_r^b}{y_{r0}^b}\right)} \tag{3}$$

subject to: $x_0 - \sum_{j=1}^{n}\lambda_j x_j - s^- = 0$; $\sum_{j=1}^{n}\lambda_j y_j^g - y_0^g - s^g = 0$;

$y_0^b - \sum_{j=1}^{n}\lambda_j y_j^b - s^b = 0$; $\lambda, s^-, s^g, s^b \geq 0$

where s^- is the relaxation variable corresponding to the input, s^g is the relaxation variable corresponding to the expected output, and s^b is the relaxation variable corresponding to the unexpected output. The objective function is strictly decremented with respect to s^{-}, s^{g}, s^{b}, and 0≤ ρ^{*}≤1. The variable return to scale (VRS) requires the following constraints: $\sum_{j=1}^{n} \lambda_j = 1$.

It should be noted that the objective function ρ^{*} is to pursue the maximum possible increase in expected output and decrease in input and non-expected output, that is, to measure GDE by using the average proportion of each input and non-expected output that can be reduced and of expected output that can be increased.

The input-output indicators of GDE include resource consumption, economic benefit, and environmental impact. Resource element inputs are the necessary basic conditions, including natural input, human input, capital input, energy input, and science and technology input. Economic benefit refers to the products and services contributing to economic value, including gross domestic product (GDP) and industrial production. Environmental impact usually refers to the waste generated in the process of economic development, which is generally characterized by the discharge of wastewater, waste gas, and solid waste. The index selection for the DEA method follows the principle (input index number + output index number) ≤⅓ number of DMUs. This study constructed an index of green development for restricted development zones (Table 1).

2.2.2 Tobit model

In order to explore the factors that restrict improvements in GDE, this paper constructs a model of the factors that influence GDE in Jilin Province. In this study, five indicators: economic factors, social factors, industrial structure, scientific and technological innovation, and environmental governance were selected to examine the factors governing the spatiotemporal pattern of GDE in Jilin Province. Among the economic factors, GDP per capita (RGDP) was used to measure the level of economic development. The square term of GDP per capita ($RGDP^2$) was used to test the environmental Kuznets curve (EKC) effect that limits GDE in development areas. Social factors, including the gap between the rich and the poor, the level of equalization of public services, and the level of urbanization, are the basic guarantee of green development. The level of urbanization is an important factor among the social factors. This paper chooses the rate of urbanization (UI) to measure the level of urbanization. Industrial structure factors affect GDE through the upgrading and rationalization of industrial structure. Two indicators were selected: the ratio of the output value of secondary industry to GDP (SIR) and the ratio of the output value of tertiary industry to GDP (TIR). Technological innovation can improve the utilization rate of resources and the development and utilization of renewable energy effectively, thus reducing the negative environmental effects associated with economic development. The number of patents is an important index for measuring scientific and technological innovation. On this account, the number of patent authorizations (PA) was selected to reflect the level of technological innovation. The level of environmental governance reflects mainly the governance of resources and environmental pollutants in the process of regional economic development. Two indicators were selected: industrial solid waste comprehensive utilization rate (ISO) and industrial sulfur dioxide removal rate (ISD).

Because the explained variable is GDE, and its value is between 0 and 1, which is obviously cut and truncated, the general econometric model can not accurately estimate it. Therefore, this paper uses the Tobit model to empirically analyze the mechanisms of different influencing factors. The formula for calculating the model is as follows:

Table 1 Evaluation index system of GDE in restricted development zones

Primary index	Secondary index	Basic index
Input indicators	Capital	Total investment in fixed assets (10 000 yuan (RMB))
	Land	Construction land area (km^2)
	Labor	Employees at the end of the year (persons)
	Technology	Professional and technical personnel (persons), number of patent authorizations (pieces)
Output indicators	Expected output	Regional GDP (10000 yuan (RMB))
	Unexpected output	Industrial wastewater discharge (10000 t), industrial sulfur dioxide discharge (t), solid waste production (10000 t)

$$GDE_i = \beta_0 + \beta_1 RGDP_i + \beta_2 (RGDP)_i^2 + \beta_3 UI_i + \beta_4 SIR_i + \beta_5 TIR_i + \beta_6 PA_i = + \beta_7 ISO_i + \beta_8 ISD_i + \varepsilon_i, \varepsilon_i \sim N(0, \sigma^2) \quad (4)$$

where GDE_i is the green development efficiency of the ith county, β_0 is coefficient of the constant term, β_1, β_2, β_3, β_4, β_5, β_6, β_7, β_8 are the regression coefficient of each influencing factor, and ε_i is the coefficient of the random error term of the ith county. In order to eliminate the effect of heteroscedasticity, all of the data are logarithmic. Under the conditions of unit Root test and Hausman test, the Tobit model is used for regression analysis of section data. The maximum-likelihood estimation (MLE) is used to estimate the coefficients (β_1, β_2, β_3, β_4, β_5, β_6, β_7, β_8).

3 Results

3.1 Temporal evolution of GDE

Using the SBM-DEA model, the GDE of 38 counties in the restricted development zones of Jilin Province between 2005 and 2015 was modeled using MATLAB software (MathWorks, Inc., Natick, MA, USA). The GDE calculated using the SBM-DEA model is the relative efficiency. The region with an efficiency value of 1.000 had the highest relative efficiency. The smaller the efficiency value, the greater the efficiency loss. In 2005, 2010, and 2015, the average GDEs of the restricted development zones in Jilin Province were 0.885, 0.791, and 0.841, respectively, reaching the optimal frontier of 88.5%, 79.1% and 84.1% and showing a V-shaped trend as a whole. Between 2005 and 2010, stimulated by the revitalization strategy of the old industrial base in Northeast China and the implementation of the strategy of 'Expanding Power and Strengthening Counties' in Jilin Province, both the urbanization and the industrialization of counties were rapidly promoted. With the rapid development of county economic development, especially the accelerated development of some counties with resource processing as the leading industry, the burden of environmental pollution and ecological service functions in the restricted development zones gradually increased. As a result, the average GDE of restricted development zones declined overall. Between 2010 and 2015, the average GDE of restricted development zones increased slowly. The improvements in efficiency in this stage of the process were attributed to Jilin Province's active promotion of supply-side structural reform, the transformation of resource-based cities, and the intensified efforts to eliminate backward industries with highly polluting and energy-consuming production capacity.

From the perspective of the eastern, central, and western Jilin Province, GDE had different temporal characteristics (Fig. 2). GDE presented a V-shaped trend in the eastern and central Jilin Province, but year on year presented a decreasing trend in the western Jilin Province. In 2005, GDE in the eastern Jilin Province was lower than that in the central and western Jilin Province. Between 2005 and 2010, GDE in the eastern, central, and western Jilin Province showed downward trends, and the efficiency values decreased from 0.820, 0.926, and 0.930 to 0.718, 0.836, and 0.842, respectively. Between 2010 and 2015, GDE in the eastern and central Jilin Province gradually improved, while GDE in the western Jilin Province continued to decline. GDE in the eastern and central Jilin Province increased to 0.873 and 0.883, respectively, while that in the western Jilin Province decreased to 0.723. The efficiency gap between eastern, central, and western Jilin Province green development gradually increased during research period. The changes in GDE of the counties in western Jilin Province between 2010 and 2015 were due mainly to the low GDE of Qianguo County, Da'an City, and Taobei District, which led to an overall decline in GDE in the western Jilin Province. These counties were still at the stage of large-scale and extensive development, and the task of improving GDE was still an arduous one.

In order to show the time variation of GDE in Jilin Province, this paper introduces the coefficient of variation. Fig. 3 shows the variability coefficient of the eastern, central, and western Jilin Province. Between 2005 and 2015, the variation coefficient of restricted development

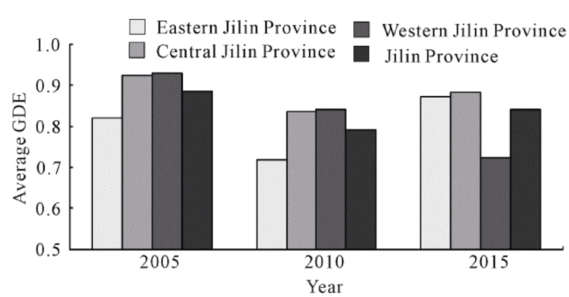

Fig. 2 Green development efficiency (GDE) evaluation results for restricted development zones in Jilin Province

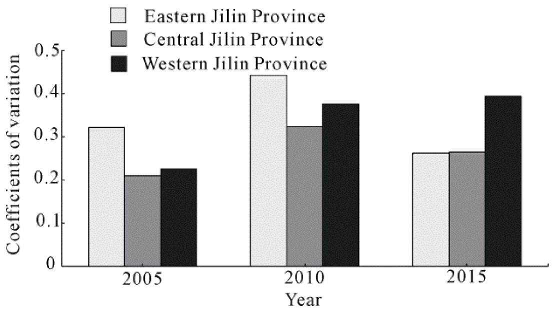

Fig. 3 Coefficients of variation of green development efficiency in eastern, central, and western Jilin Province

zones increased from 0.28 to 0.32, showing that the differences in GDE within the restricted development zones gradually increased. Further analysis was carried out as to the internal differentiation characteristics of the eastern, central, and western Jilin Province. The coefficient of variation in the eastern Jilin Province increased from 0.32 in 2005 to 0.44 in 2010 and decreased to 0.26 in 2015. This showed that GDE in the eastern Jilin Province was larger in 2010 and smaller in 2015. GDE in the central Jilin Province was relatively small, which also showed a trend of first increasing and then decreasing. GDE in the western Jilin Province was greater, and the coefficient of variation rose from 0.23 to 0.39. In 2015, the number of low- and lower-efficiency counties in the western Jilin Province increased.

3.2 Spatial differentiation characteristics of GDE

According to the results for GDE of the restricted development zones in Jilin Province between 2005 and 2015, and with reference to the efficiency measurement standards of existing studies (Yang and Wen, 2017; Ren et al., 2017), GDE is divided into five levels: higher efficiency, high efficiency, medium efficiency, low efficiency, and lower efficiency (Table 2).

Fig. 4 shows the spatial differentiation of GDE in restricted development zones of Jilin Province. There were 18 higher-efficiency counties in restricted development zones, accounting for 47% of the study area. There were 11 counties with high efficiency, accounting for 29% of the study area. There were five counties with medium efficiency, accounting for 13% of the study area. There were only four counties with low efficiency, accounting for 11% of the study area. It can be seen that the overall GDE of the restricted development zones in Jilin Province was quite good, and 76% of the counties were in either the high- or higher-efficiency bands. From the perspective of spatial distribution, the GDE of these regions was similar to that of neighboring regions. The high- and higher-efficiency areas showed the characteristics of agglomeration and continuous development, and the counties that did not reach the optimal frontier were mostly in the low-efficiency areas. In the central part of the province, Changchun City and Jilin City are at the core and spread to the periphery. The counties around the two core cities of Changchun and Jilin, such as Nong'an, Yushu, Dehui, Jiaohe, and Huadian, had high and higher GDE. These counties had relatively developed transportation networks, which were easily able to accommodate the radiation and diffusion of the core cities. They also had good industrial economic foundations, high economic output, relatively high industrial sewage treatment rates, and comprehensive utilization rates of solid waste, so the unexpected output was less. The GDE of peripheral counties, such as Yongji, Shulan, Shuangliao, Dongfeng, Dongliao, was relatively low. The GDE of counties in the eastern region was characterized by being high in the middle and low in both wings. The GDE of Jingyu, Linjiang, Fusong, Changbai, Jiangyuan, Hunjiang, Antu, and Ji'an in the middle was relatively high, and that of Dunhua, Wangqing, Helong, Liuhe, and Tonghua in the two wings was relatively low. The GDE of the western region was higher in the south and lower in the north. The GDE of Changling, Qian'an, Fuyu, and Tongyu in the south was higher than that of Zhenlai, Taonan, Da'an, and Taobei in the north.

The resource-based cities were the main areas with relatively low GDE. This kind of regional resource-based industry has been an important pillar of economic development, and most employees were engaged in resource-related industries. The environmental cost of regional development was high, resource dependence was strong, and the mode of economic growth

Table 2 Table of graded evaluation criteria for GDE in restricted development zones

Grade	Lower efficiency	Low efficiency	Medium efficiency	High efficiency	Higher efficiency
Interval	0–0.300	0.301–0.500	0.501–0.700	0.701–0.999	1

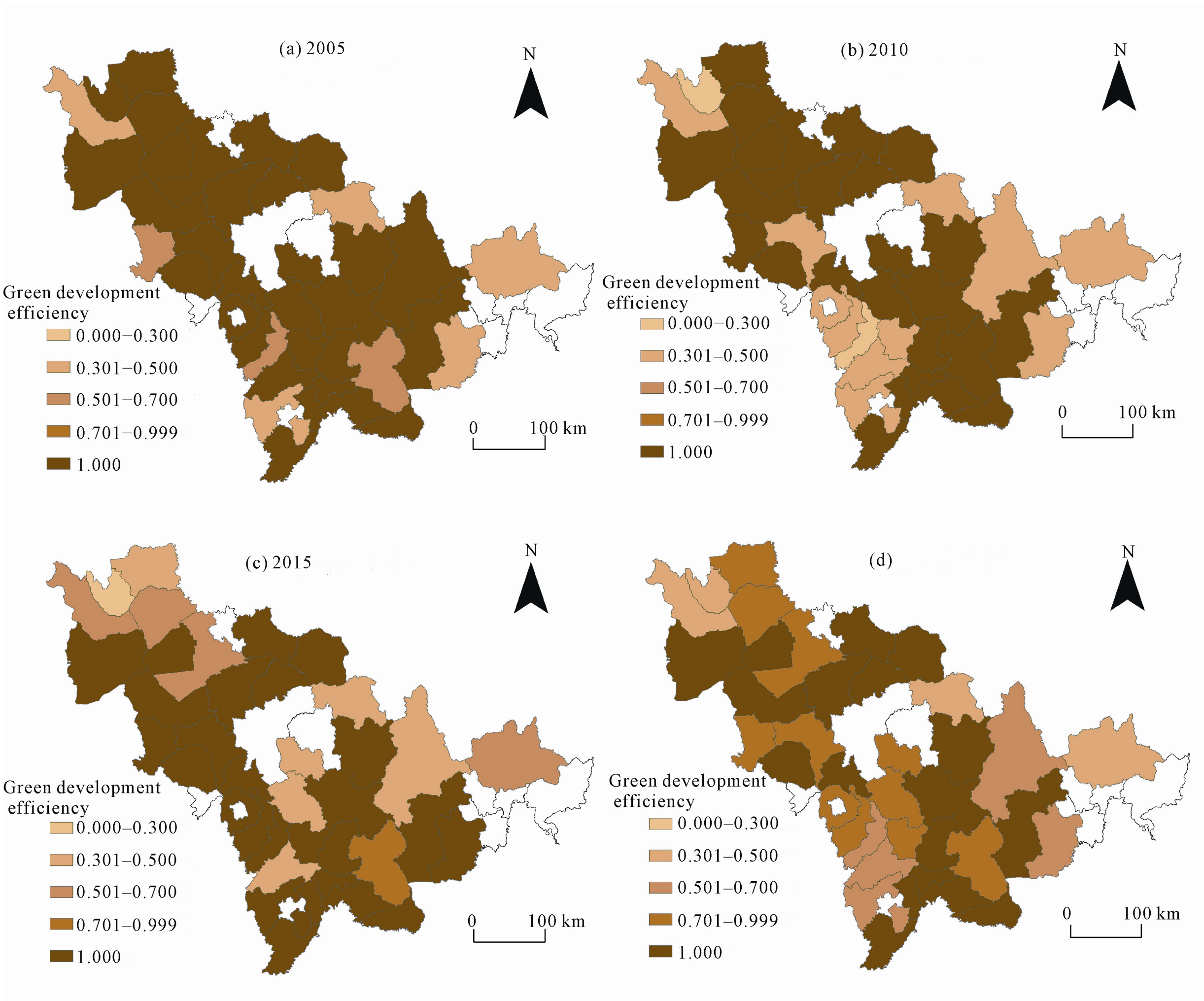

Fig. 4 Spatial differentiation of green development efficiency in restricted development zones of Jilin Province in (a) 2005, (b) 2010, (c) 2015, and (d) the average of the three periods

was extensive and single, forming an obvious low-efficiency area of green development. In terms of regions, including Shulan, Panshi, Dongfeng, and Dongliao in the central Jilin Province, Wangqing, Dunhua, and Helong in the eastern Jilin Province, Zhenlai, Taonan, Da'an, and Taobei in the western Jilin Province, GDE was of low and medium efficiency. This reflected the fact that there were problems of weak development common to the resource-based counties in Jilin Province, and the pressure of green development remained large. As a typical city exhausted of coal resources, the GDE of Shulan City in 2005, 2010, and 2015 was low. Although it had been transformed and developed for many years, continuous alternative industries were still in the growth stage, the endogenous power of economic growth was still insufficient, and the quality and efficiency of economic development needed to be further improved. The GDE of cities relying on forest industry resources, such as Dunhua and Wangqing in the Eastern, was also low. With the depletion of the available forest resources, especially after the prohibition of commercial logging in Changbai Mountain forest area, the economic development of forest areas in general became very difficult, despite the fact that the counties strove to cultivate alternative industries. Dunhua focused on developing food processing, biopharmaceuticals, tourism, and other industries, while Wang Qing focused on developing edible fungi, photovoltaic power generation, and e-commerce. However, due to the long-standing problems associated with resource-based cities, the task of economic development and environmental governance remained a formidable one. The GDE of Zhenlai, Taonan, Da'an, Taobei, and other oil and gas resource counties in the Western was high in 2005. However, because the oil resources were in the middle and late stages of exploitation, their ability to contribute to urban economic development was gradually being reduced and their economic output was not high. Therefore, their GDE gradually reduced in the later stages of exploitation.

3.3 Influencing factors

Based on the Tobit model constructed above, according to the cross-sectional data of 38 counties in the restricted development zones of Jilin Province in 2005, 2010, and 2015, this study used Stata15.1 econometric analysis software to empirically test the influencing factors of GDE. The results are presented in Table 3.

There was a positive correlation between RGDP and GDE, which passed the significance test. For every 1% increase in RGDP in 2005, 2010, and 2015, GDE increased by 0.3935, 0.7085, and 0.3469 percentage points, respectively, which showed that the restricted development zones of Jilin Province were in the rising period of economic development. As the latter brought technological progress and the optimization and upgrading of the province's industrial structure, GDE continued to increase. In order to further test whether there was an 'EKC' effect involving economic development level and GDE, the square term of per capita GDP $(RGDP)^2$ was introduced into the factor analysis and measurement model. The results showed that there was a significant positive correlation between $(RGDP)^2$ and GDE. That is, there was a 'U' curve relationship between economic development and GDE. Therefore, an 'EKC' effect existed between GDE and the economic development level of restricted development zones in Jilin Province.

The correlation coefficient between UI and GDE was negative and passed the significance test. This showed that the level of urbanization had a significant inhibitory effect on the promotion of GDE in the restricted development zone. However, from the change in the 'influence of urbanization level' coefficient, this inhibitory effect was gradually weakening. For every 1% increase in UI, the GDE dropped by 0.3569, 0.3493, and 0.2387 percentage points in 2005, 2010, and 2015, respectively. Existing studies show that there is a nonlinear relationship between urbanization development and GDE. With urbanization rates of 77.3% and 93.4% as thresholds, the impact of urbanization on GDE can be divided into three stages: negative inhibition in the early stage, weak promotion in the middle stage, and positive promotion in the late stage (Zhao et al., 2019). In 2015, the urbanization rate of restricted development zones in Jilin Province was 35.53%, which was still in the early stage of urbanization. This stage focused on the spatial agglomeration of economic factors and improvement of the urbanization level. The agglomeration and spillover effect of urbanization did not play a strong role in improving GDE.

Table 3 Estimated results for the influencing factors of GDE in restricted development zones in Jilin Province

Explanatory variable	2005		2010		2015	
	Coeff.	*t*	Coeff.	*t*	Coeff.	*t*
RGDP	0.3935^{***}	2.65	0.7085^{***}	5.43	0.3469^{*}	1.84
$(RGDP)^2$	0.1916^{**}	2.40	0.3192^{***}	3.62	0.1552^{*}	1.59
UI	-0.3569^{**}	−3.28	-0.3493^{**}	−2.52	-0.2387^{*}	−1.97
SIR	0.1538	1.01	0.1621	0.52	0.0277	0.08
TIR	0.3529	1.92	0.5499	1.67	−0.0198	−0.06
PA	-0.0323^{*}	−0.92	−0.027*	−0.67	0.0099	0.27
ISO	0.0026	−1.66	−0.0557	−0.74	0.1012^{*}	1.51
ISD	−0.1184	1.82	0.0748	1.06	−0.0114	−0.08
β_0	1.8272^{*}	1.50	1.6126	0.80	2.0288	0.89

Notes: Coeff. is the coefficient of the estimated explanatory variables; ***, **, * indicate passing the significance level test of 99%, 95%, and 90%. RGDP, GDP per capita; $(RGDP)^2$, square term of GDP per capita; UI, the rate of urbanization; SIR, the ratio of the output value of secondary industry to GDP; TIR , the ratio of the output value of tertiary industry to GDP. PA, the number of patent authorizations; ISO, industrial solid waste comprehensive utilization rate; ISD, industrial sulfur dioxide removal rate

The relevant indicators of industrial structure had no significant impact on GDE. The correlation coefficient between SIR and GDE was positive, but it failed to pass the significance test. For every 1% increase in SIR, the GDE of the restricted development zones in Jilin Province increased by 0.1538, 0.1621, and 0.0277 percentage points in 2005, 2010, and 2015, respectively. It can be seen that the positive effect of SIR on GDE gradually weakened. There was a positive correlation between TIR and GDE in 2005 and 2010. For every 1% increase in TIR, the GDE of the restricted development zones in Jilin Province increased by 0.3529 and 0.5499 percentage points in 2005 and 2010, respectively, which was greater than the impact of SIR on GDE. This showed that Jilin Province had achieved some progress in adjusting industrial structure and encouraging the development of tertiary industry. However, due to the relatively high proportion of traditional service industries in the tertiary industrial structure, the development of modern service industries lagged behind, relatively speaking, thus limiting the promotion of GDE.

The effect of technological innovation on GDE gradually changed from negative to inhibitory to positive promotion significantly over time. From the perspective of the entire restricted development zone in Jilin Province, improving GDE as a means of environmental regulation played a role in promoting urban technological innovation, and a 'backward mechanism' of technological innovation was forming. This was consistent with the 'Porter hypothesis', that is, strict environmental regulations can induce efficiency and encourage innovations that help improve commercial competitiveness.

Environmental governance reflects mainly the governance of resources and environmental pollutants in the process of regional economic development. The two indexes of ISO and ISD had little influence on GDE but had a weak positive effect on the whole. Only in 2015 was the impact of ISO on GDE significantly positively correlated, passing the 90% significance level test. This showed that, although the control of environmental pollutants in the restricted development zones of Jilin Province reduced the unexpected output, the economic benefits did not exceed the environmental protection costs. The effect of pollution control on GDE did not play a role. In the future, it will still be necessary to continue to improve environmental governance capacity and investment.

4 Discussion

This paper uses the SBM-DEA model to analyze the spatial and temporal pattern of GDE in Jilin Province. The results showed that the time sequence of GDE evolution in these restricted development zones followed a V-shaped pattern and that the differences in GDE between different regions of the zones gradually increased. A total of 76% of the counties in the restricted development zone had high or higher efficiency. GDE had obvious spatial agglomeration and spillover effects. Most resource-based cities were in low-efficiency areas. For resource-based restricted development zones, it is necessary to promote transformation and development by classification, and so gradually establish an ecological industrial system. Shulan, Dongfeng, Dongliao, and other cities exhausted of coal resources should cultivate new leading industries according to their own resources, technology, location, and industrial basis so as to realize a stable transformation of their economic structure. Against the background of the country's overall halt to natural forest commodity logging, Dunhua, Helong, Wangqing, and other forest industry resource cities should speed up the transformation from forest logging to forest resources management, deep processing of forest resources, development and utilization of special forest and forest ecological resources, and use the renewable and multifunctional characteristics of forest resources to guide and drive county-level economic transformation and development. Petroleum resource-based cities should encourage the development of alternative industries based on petroleum resources, especially the development of deep-processing industries, improve the industrial and technical levels, and realize the smooth transition from resource-based cities to processing cities.

The concept of the 'Major Function Oriented Zone' has been proposed for many years. Most researchers focus on the role of natural factors in analyzing those factors influencing restricted development zones, but such an analysis is insufficient without also considering the human factors involved (Guo et al., 2014; Mi et al., 2017; Song et al., 2017). This paper explores the factors that influence the spatial and temporal pattern evolution of GDE in restricted development zones in

Jilin Province from five different aspects: economic factors, social factors, industrial structure, scientific and technological innovation, and environmental governance. Our results show that economic factors were the core drivers of GDE. The correlation coefficient between $(RGDP)^2$ and GDE was significantly positive, and there was an obvious 'EKC' effect. In the future, it will be necessary to build and continue to improve a green GDP assessment system that includes energy conservation and pollutant emissions reduction to improve the quality and efficiency of economic development so as to reduce the environmental pollution and pressure caused by the latter. The rate of urbanization (UI) had a significant negative inhibitory effect on GDE in the restricted development zones, which gradually weakened. This was related to the fact that the restricted development zones of Jilin Province were in the early stage of urbanization. The effect of agglomeration and urbanization spillover on GDE was not demonstrated. In the future, we should promote ecological urbanization, gradually transform the pressure of urban development on economy and society into driving force, and play a positive role in improving GDE. The influence of industrial structure on GDE was not significant. In the future, each county in the restricted development zone of Jilin Province should formulate a detailed industry negative list, strictly prohibit the transfer of high energy consumption and highly polluting projects to the restricted development zones of Jilin Province, actively guide, support, and encourage environmental protection projects, and focus on supporting the development of resource-saving and environmentally friendly alternative industries in the restricted development zones. The effect of technological innovation on GDE showed a fluctuating trend, from negative inhibition to positive promotion. We found that the 'backward mechanism' of technological innovation was beginning to form, which was consistent with the 'Porter hypothesis'. Environmental governance had little effect on GDE, and overall had a weak positive impact. With the enhancement of governments at all levels environmental governance, industrial waste gas and solid waste emissions gradually decreased, which led to a corresponding reduction in the unexpected outputs of GDE, thus improving GDE overall.

As the region with the most acute dichotomy between humans and land, our study of the spatiotemporal evolutionary characteristics of GDE and the factors that influence it in restricted development zones makes realistic demands. It is not only a beneficial exploration of how to realize the sustainable development of restricted development zones, but also a positive response to Jilin Province, and even to China as a whole, in formulating a quality development strategy for those restricted development zones according to local conditions. Based on our analysis of previous studies of green development, this study used the SBM-DEA model to analyze the spatiotemporal patterns of GDE in Jilin Province. The formation of these patterns was affected by many factors, including economic factors, social factors, industrial structure, technological innovation, and environmental governance. Each factor, on its own or coupled with other factors, restricts the process of green development and improvements in GDE. This study is a preliminary exploration in readiness for the next stage of supply-side structural reform, elimination of backward production capacity, cultivation of new kinetic energy, and formulation of green environmental protection policies in Jilin Province so as to decouple economic growth from environmental pollution.

Because the research scale of this study was at the county level, it was difficult to obtain basic data for indicators such as investment in science and technology, investment in environmental protection, energy and resources, and environmental governance. The above indicators were not included in the GDE evaluation and analytical model, and the selection of indicators had certain limitations. In addition, in selecting the time samples, only section data for 2005, 2010, and 2015 were selected, and thus the characteristics of the continuous time evolution of GDE in Jilin restricted development zones need to be further described and analyzed. In the future, we will continue to carry out theoretical and practical research on green development, focusing on its comprehensiveness, coordination, systematicness, and orientation. In addition, we will further clarify and improve the definition, theoretical basis, and promotion path of green development in restricted development zones from the perspective of geography, which is expected to further enrich the theory and study of human-land relationships and provide methodological support and research perspectives for solving ecological and environmental problems.

5 Conclusions

The spatial and temporal differences of GDE in the restricted development zones of Jilin Province were obvious. Between 2005 and 2015, the temporal evolution of GDE in restricted development zones in Jilin Province showed a V-shaped trend. GDE in Eastern, Central, and Western Jilin Province showed different evolutionary characteristics. The Eastern and Central Jilin Province showed a V-shaped trend, while the Western Jilin Province showed a declining trend year on year. From the perspective of spatial differentiation, most of restricted development zones in Jilin Province were in counties with high or higher efficiencies. Most resource-based counties were in low- or lower-efficiency areas. In the Central Jilin Province, Changchun City and Jilin City are at the core and spread to the periphery. The GDE of counties in the Eastern Jilin Province was characterized by high efficiency in the middle and low efficiency in both wings. The GDE of the Western Jilin Province was higher in the south and lower in the north.

Different factors had different effects on green development efficiency. Economic factors were the core drivers of GDE. The correlation coefficient between $(RGDP)^2$ and GDE was significantly positive, and there was an obvious 'EKC' effect. The UI significantly inhibited GDE in the restricted development zones, which gradually weakened. The influence of industrial structure on GDE was not significant. The effect of technological innovation on GDE showed a fluctuating trend, from negative inhibition to positive promotion. We found that a 'backward mechanism' of technological innovation was beginning to form, which was consistent with the 'Porter hypothesis'. Environmental governance had little effect on GDE, and the overall performance was a weak positive impact. Therefore, restricted development zone in Jilin Province should pay attention to the quality of economic development, the transformation of industrial ecology and the improvement of technological innovation level, and gradually break the restriction of resources and environment on economic development.

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