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Impact of Government Environmental Auditing on the Efficiency of Regional Green Development—Spatial Econometric Analysis Based on Tobit-SDM Model

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Abstract: *Green development is a new approach to lead the ecological civilization construction. By utilizing the panel data of 30 provinces and cities in China from 2010 to 2021, the Tobit-Spatial Durbin model was constructed to test the impact of government environmental auditing on the efficiency and spillover of green development. The study revealed that government environmental auditing not only had a significant positive impact on the efficiency of local green development but also promoted the efficiency of green development in neighboring areas, thereby forming a "high-high" agglomeration. Therefore, improving the audit system, optimizing the allocation of audit resources, and creating a good audit environment are important ways to promote the efficiency of green development.*

Keywords: *Government environmental auditing, Green development efficiency, Super-efficiency SBM-DEA model, Tobit-Spatial Durbin Model*

1. Introduction

With the rapid growth of the national economy, China's demand and consumption of energy and resources are increasing, and the contradiction between economic growth and environmental protection has become a bottleneck restricting the high-quality development of the economy. Green development is the coordination and unification of"green" and "development". Multiple goals of economic growth, social stability, and good ecology can be achieved by reducing the excessive use of resources and strengthening environmental protection and ecological governance[1]. China's green development has made remarkable achievements. For example, in 2016, the average growth rate of the green GDP economy reached 7.58%, and in 2017, the proportion of the green GDP economy in the total national GDP reached 10%. However, in the face of problems such as resource shortage and environmental degradation, its efficiency needs to be improved.

After reviewing the existing literature, it has been found that endogenous factors (economic development level [2], environmental regulation [3], energy structure [4]) and exogenous factors (foreign direct investment [5], opening up [6], import and export trade [7]) all affect the green development efficiency, but there are few studies on the internal supervision mechanism of the government. As an important supervision mechanism of environmental governance in China, government environmental auditing is an important tool to strengthen the environmental responsibility of local governments and promote ecological civilization construction. Under the background of tightening environmental governance supervision, does government environmental auditing affect the efficiency of regional green development? Especially in the presence of strategic interaction between jurisdictions, externality of public goods, and spillover of green development efficiency, can audit promote the spatial spillover of green development efficiency? This study is helpful in identifying the policy effect of government environmental auditing and provides inspiration for promoting the green development of China's economy.

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2. Research Hypothesis

2.1. Government Environmental Auditing and Green Development Efficiency

Government environmental auditing is not only an important part of national environmental governance but also an "immune system" with functions of prevention, disclosure, and resistance [8]. Its governance function strengthens the environmental responsibilities entrusted to local governments, brings about changes in their governance tendencies and behaviors, and ultimately promotes the efficiency of regional green development. Firstly, environmental auditing supervises the collection, distribution, management, and use of financial ecological environmental protection funds of local governments and exposes their negligence and corruption with the help of the announcement system, which is the main manifestation of the audit's "revelation" and "prevention". From the perspective of government trust guarantee in environmental governance, local governments will invest limited financial funds in the field of environmental governance with higher public goods demands, which will effectively alleviate the problems such as waste of resources and low efficiency and promote the green development efficiency. Secondly, the function of "resistance" requires environmental auditing to investigate the scientificity and integrity of local environmental governance regulations, principles and policies, as well as the effectiveness of implementation through compliance audits. According to the theory of external pressure[9], environmental auditing will objectively increase the pressure of environmental governance faced by local governments to enhance the accuracy of local governments' policy formulation, improve their governance efficiency in green development, and promote the efficiency of green development. Finally, environmental performance auditing audits the implementation and effectiveness of the relevant government departments to fulfill their service, management, and supervision responsibilities and carry out various governance measures, find out the problems and weak links in local government management properly, issues audit results report, makes decisions on treatment and punishment, and proposes specific rectification suggestions. Meanwhile, it continues to track and check the rectification situation and gives full play to the government audit's functions of "revelation" and "prevention" to urge local governments to improve environmental management performance, enhance the governance efficiency of environmental auditing, and promote the efficiency of green development. Accordingly, Hypothesis H_1 is proposed:

H_1: Government environmental auditing is conducive to promoting the efficiency of regional green development.

2.2. Spillover of Government Environmental Auditing and Green Development Efficiency

Due to the spatial spillover of green development efficiency[10], and considering the proximity of inter-regional spatial location and the strategic interaction between governments, environmental auditing may have both positive and negative effects on the spillover of efficiency while improving the efficiency of local green development. On the one hand, based on the positive externality theory, improving the ecological environment in one region may benefit the surrounding areas. Under the background of national ecological civilization construction, the green development efficiency of the surrounding areas affects the region through the "learning effect", that is, the local government may take the initiative to learn from the surrounding areas with high green development efficiency based on the pressure of government performance assessment. The function of the immune system of environmental auditing objectively motivates the willingness of local governments to improve the efficiency of green development, strengthens the "learning effect", and then makes the efficiency overflow positively, thus improving the efficiency of green development in neighboring areas. On the other hand, regions with high green development efficiency usually possess more high-quality resources and are more likely to attract the inflow of surrounding capital, talents, and industries, thereby causing the "polarization effect" of inter-regional resource factors[11], aggravating the alienation of regional green development efficiency, and inhibiting the improvement of green development efficiency in neighboring areas. Based on this, the opposite hypotheses $H_{2a}$and $H_{2b}$are proposed:

H_{2a}: When the positive spillover brought by the "learning effect" is greater than the negative spillover brought by the "polarization effect", the government environmental auditing may positively affect the efficiency spillover.

H_{2b}: When the positive spillover brought by the "learning effect" is less than or equal to the negative spillover brought by the "polarization effect", the government environmental auditing may negatively or non-significantly affect the efficiency spillover.

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3. Research Methods and Data Sources

3.1. Model Building

3.1.1. Super-efficiency SBM-DEA model

Since the traditional DEA model did not consider the factor "relaxation" and could not reasonably solve the efficiency evaluation problem under the condition of undesired output, Tone (2001) proposed the following non-radial super-efficiency DEA model:

$$\begin{aligned} &\min \rho^* = \frac{1+\frac{1}{m}\sum_{i=1}^{m}\frac{S_i^-}{x_k}}{1-\frac{1}{s}\sum_{r=1}^{s}\frac{S_r^+}{y_{rk}}} \\ &s.t.\sum_{j=1,j\neq k}^{n} x_{ij}\lambda_j - s_i^- \le x_{ik} \\ &s.t.\sum_{j=1,j\neq k}^{n} y_{ij}\lambda_j + s_i^+ \ge y_{ik} \\ &\text{s.}t.\lambda, s_i^-, s_i^+ \ge 0, s.t.i = 1,2,\ldots,m; r = 1,2,\ldots,s; j = 1,2,\ldots,n(j \neq k) \end{aligned} \tag{1}$$

Where ρ^*represents the target efficiency value; x and y represent the number of inputs and outputs; λ represents the weight; i and r represent the input and output DMU; $s^-$and $s^+$are relaxation variables.

3.1.2. Spatial Tobit-SDM model

Based on the method of Bai Junhong et al. (2017) [12], the following spatial econometric model is introduced to re-investigate the relationship between environmental auditing intensity and green development efficiency from the perspective of space, and the model is as follows:

Where EFF represents the green development efficiency; Audit represents the intensity of government environmental auditing; ρ represents the spatial autoregressive coefficient, which reflects the spatial dependence between sample observations; W is a n×n spatial weight matrix, which contains 0-1 adjacency weight matrix W_1, geographical distance weight matrix W_2, and economic distance weight matrix W_3.

3.2. Data Sources and Variable Selection

In this paper, the data of 30 provincial administrative units (excluding Tibet, Hong Kong, Macao, and Taiwan) in Chinese mainland from 2010 to 2021 as the research sample in table 1. The relevant data of government environmental auditing are derived from *China Audit Yearbook* and the website of the National Audit Office. The relevant data of green development efficiency are mainly derived from *China Statistical Yearbook*, *China Environmental Statistics Yearbook*, and so on.

Table 1: Evaluation index system of green development efficiency

Classification		Index types	Index constitution
Input index		Labor force input	Urban employed persons (10,000)
		Energy input	Total energy consumption (10,000 tons of standard coal)
		Capital input	Fixed assets stock (ten thousand Yuan)
		Technology input	Research and experimental development (R&D) personnel full-time equivalent jobs (person-year)
Final output index	Expected output	Economic benefit	GDP (billion Yuan)
	Unexpected output	Wastewater discharge	Industrial wastewater discharge (100 million standard cubic meters)
		Exhaust emission	Industrial sulfur dioxide discharge (10,000 tons)
		Solid waste discharge	Production of general industrial solid waste (10,000 tons)

(1)Disbanded variable: green development efficiency (Eff). Based on the existing research [13], labor force, energy, capital, and technology are used as input indicators, GDP is used as expected output, and

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the "three wastes" produced in the industrial production process are undesirable outputs.

(2) Core explanatory variables: government environmental auditing intensity (Audit). Considering the reliability and availability of the data, the practice of Cai Chun (2021) [14] is drawn on to construct the government environmental auditing intensity index of each province, region, and city.

(3) Control variables. Economic development (Ed), government expenditure (Go), industrial structure (Is), opening up (Op), urbanization rate (Ur), and control variables are logarithmically processed. Their specific meanings and calculation methods are shown in Table 2.

Table 2: Variable definitions

Variation code	Variable meaning	Calculation method
Eff	Green development efficiency	Using the super-efficiency SBM-DEA model to measure the regional green development efficiency.
$Audit_{i,\ t-1}$	Government environmental auditing intensity	Total number of types of environmental audit projects carried out by the National Audit Office and the Provincial Audit Office in the area where the enterprise is located
Ed	Economic development	Regional GDP per capita
Go	Government expenditures	Government budget expenditure/regional GDP
Is	Industrial structure	Value added of tertiary industry /value added of secondary industry
Op	Opening up	Foreign direct investment/regional GDP
Ur	Urbanization rate	Urban permanent resident population/total permanent resident population

4. Experimental Results and Analysis

4.1. Analysis of Green Development Efficiency Measurement Results

As shown in Figure 1, China's green development efficiency has increased significantly during the study period, with a mean value of 0.74, and there is still room for improvement from the effective state. The green development efficiency of the three major regions shows a fluctuating upward trend, but there are large differences between the regions: the eastern part presents a "U" shape and the efficiency is the highest; the central part presents an "M" shape, and the average efficiency ranks the last; the efficiency change in the western part is relatively gentle. Therefore, it can be seen that compared with the economically developed eastern regions, the green development efficiency in the central and western regions still needs to be improved.

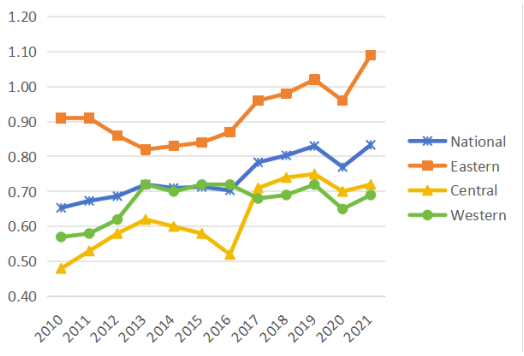

Figure1: Green development efficiency of national and three regions

4.2. Descriptive Statistics

Table 3 shows the descriptive statistical results of the variables. The mean value of green development efficiency (Eff) is 0.740, and there is a large room for improvement. The efficiency of the eastern region is higher than that of the central and western regions, with prominent imbalance of regional green development. The average value of the environmental auditing intensity index (Audit) is 3.144, indicating that the overall intensity of China's environmental auditing is low; The difference

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between the extreme values reflects that the environmental auditing intensity of several provinces and cities has obvious differentiation characteristics.

Table 3: Descriptive Statistics of Variables

Variable	National				Eastern		Central		Western	
	Mean value	Standard deviation	Minimum	Maximum	Mean value	Standard deviation	Mean value	Standard deviation	Mean value	Standard deviation
Eff	0.740	0.948	0.462	1.094	0.921	0.817	0.628	0.732	0.672	0.594
Auditi, t-1	3.144	0.363	0.000	8.000	3.280	0.472	3.198	0.593	2.970	0.384
Ed	10.784	0.479	9.464	12.142	11.168	0.424	10.594	0.302	10.536	0.379
Go	0.259	0.112	0.105	0.758	0.190	0.062	0.236	0.057	0.345	0.125
Is	1.314	0.723	0.527	5.244	1.628	1.069	1.061	0.301	1.184	0.234
Op	0.019	0.015	0.000	0.080	0.028	0.017	0.023	0.010	0.007	0.007
Ur	0.589	0.124	0.338	0.896	0.696	0.118	0.539	0.064	0.519	0.085

4.3. Spatial Correlation Test

To investigate the agglomeration degree of environmental audit and green development efficiency in geographical space, this paper determines whether the global spatial autocorrelation exists by testing the Moran'I index. As shown in Table 4, the P values of green development efficiency (Eff) under the three spatial weight matrices are significantly positive at the 1% level, indicating that green development efficiency has a spatial positive correlation; the Moran index value of the environmental auditing intensity (Audit) is not 0 and has passed the significance test; the Moran'I of the remaining variables also has significant spatial correlation under different spatial weight matrices, indicating that the impact of environmental audit on green development efficiency needs to consider spatial factors.

Table 4: Spatial autocorrelation test based on three weight matrices

Variable	Moran'I								
	0-1 adjacent weight matrix			Geographical distance weight matrix			Economic distance weight matrix		
	I value	Z value	P value	I value	Z value	P value	I value	Z value	P value
Eff	0.287	6.521	0.000	0.180	5.209	0.000	0.224	6.258	0.000
Auditi,t-1	0.147	3.941	0.000	0.149	4.950	0.000	0.183	6.544	0.000
Ed	0.321	8.650	0.000	0.326	10.929	0.000	0.361	13.031	0.000
Go	0.658	17.361	0.000	0.629	20.599	0.000	0.680	24.077	0.000
Is	0.539	14.229	0.000	0.405	13.327	0.000	0.221	7.900	0.000
Op	0.422	11.158	0.000	0.208	6.882	0.000	0.108	3.924	0.000
Ur	0.107	2.967	0.003	0.092	3.171	0.002	0.037	1.442	0.049

4.4. Test Results of Spatial Econometric Model

According to the estimation order of the spatial panel data model, the spatial autocorrelation is measured by the LM test. As shown in Table 5, the four statistical results of the LM test are significant at the level of 5% and above, indicating that spatial econometric analysis should be carried out. Secondly, the Hausman test results reveal that the fixed effect should be selected; by comparing the LR and Wald statistics, it is further determined that the Tobit-SDM model is effective. Considering the robustness of the results, the geographical distance weight matrix and three spatial econometric models are selected for testing.

Table 5:Related test results of spatial econometric model

Test	Statistics		Test	Statistics	Statistics
	RE	TE		RE	TE
LM(lag)test	11.562**	7.243**	LR-spatial-lag	36.425**	25.512***
Robust LM(lag)test	9.634**	7.682***	LR-spatial-error	52.851**	24.754**
LM(error)test	7.498**	6.429**	Wald-spatial-lag	9.125***	10.827**
Robust LM(error)test	13.831**	6.398***	Wald-spatial-error	14.279**	16.742***
Hausman	17.956***	15.092*			

Note: *, * * and * * * are significant at 10%, 5% and 1% significance levels, respectively.

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Table 6: Regression results of various measurement models

Variable	Geographical distance weight matrix		
	Tobit-SDM	Tobit-SAR	Tobit-SEM
	Eff	Eff	Eff
Auditi,t-1	1.535***	1.478***	1.426***
	(4.51)	(3.46)	(3.52)
Ed	0.591***	0.457**	0.542**
	(2.89)	(2.02)	(2.38)
Go	0.229**	0.315*	0.314**
	(2.14)	(1.87)	(2.29)
Is	0.884***	0.563**	0.607***
	(4.05)	(2.35)	(5.32)
Op	0.764***	0.695***	0.553**
	(2.72)	(3.94)	(2.43)
Ur	0.375**	0.219***	0.403**
	(2.38)	(3.95)	(2.05)
Constant	8.472***	7.116***	13.899***
	(6.54)	（5.41）	（6.07）
ρ/λ	2.563***	1.831***	1.536**
	(4.72)	(3.77)	(2.24)
sigma	0.809***	0.652***	0.734***
	(9.34)	(10.26)	（6.28）
R2Adj	0.9352	0.9026	0.8164
Log-L	235.6425	204.7481	198.5374

The results are shown in Table 6. The regression coefficients of environmental auditing on green development efficiency under the three spatial econometric models are significantly positive at the 1% level, indicating that environmental auditing is conducive to promoting the improvement of green development efficiency, so Hypothesis H1 is supported. Meanwhile, the spatial autoregressive coefficient (ρ/λ) is significantly positive at the level of 5% and above, indicating that the improvement of green development efficiency in this region has a positive impact on the efficiency of neighboring areas. To further explore the impact of environmental auditing on the spillover of green development efficiency, the Tobit-SDM model under the geographical distance weight matrix is decomposed by using the method of Lesage and Pace [15], and the estimation results are shown in Table 7.

Table 7:Direct and indirect effects of government environmental auditing on green development efficiency

Variable	Direct effect		Indirect effect	
	Coefficient	z value	Coefficient	z value
Auditi,t-1	1.291***	3.52	0.306**	2.45
Ed	0.872***	2.96	-0.435*	1.74
Go	0.104**	2.09	0.135**	2.09
Is	0.583*	1.85	0.197	1.36
Op	0.397***	2.73	0.286**	2.33
Ur	0.116**	2.31	0.221***	5.65

The regression coefficients of the direct and indirect effects of environmental auditing (Audit) are 1.291 and 0.306, respectively, which are significant at the level of 5% and above. This means that environmental auditing positively affects the green development efficiency of the region and neighboring areas, which further supports H1 verifies H2a[17]. Government environmental auditing has a significant positive impact on the spillover of green development efficiency[18,19], that is, environmental auditing enhances green development efficiency while promoting the efficiency of local green development, thereby forming a high-high agglomeration state in space, which highlights the importance and necessity of carrying out cross-province and cross-regional environmental auditing.

5. Stability Test

To test the robustness of the conclusion, firstly, the green development efficiency is measured by the Malmquist-Luenberger method [16]; Secondly, it is re-tested by the economic distance weight matrix; Finally, based on the existing control variables, the population density (Pd) (total permanent resident population/administrative area at the end of the year), and the level of infrastructure construction (Ic) (highway mileage, railway operating mileage, inland waterway mileage sum/administrative area) are

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increased. The above test results are consistent with the previous conclusions[20].

6. Conclusions and Suggestions

Based on the panel data of 30 provinces and cities in China from 2010 to 2021, a Tobit-Spatial Durbin model is constructed to test the impact of government environmental auditing on regional green development efficiency and spillover. The study finds that there is still room for improvement in the effective state of China's green development efficiency, and "high in eastern region and low in central and western regions, with significant regional differences; Environmental auditing can not only promote the green development efficiency in this region but also enhance the green development efficiency in surrounding areas.

Based on this, the following policy recommendations are proposed. First, the audit system should be perfected and the audit supervision should be enhanced. Audit institutions should further improve environmental auditing laws and regulations to clarify the important role of audit institutions in promoting comprehensive green and low-carbon transformation and sustainable development of economic and social development. Meanwhile, the supervision of environmental auditing should be strengthened, and the breadth and depth of environmental auditing in provinces and cities with low green development efficiency and incomplete audit constructive role should be expanded to ensure that environmental auditing can improve green development efficiency. Secondly, the allocation of audit resources should be optimized and regional coordination should be strengthened. Audit institutions should speed up the deployment and implementation of the strategy of "enhancing audit with science and technology", increase financial support and construction assessment for major green development projects of local governments, and actively carry out a cross-regional joint audit to strengthen the role of environmental audit in promoting the spillover of green development efficiency, so as to promote the formation of a normalized and standardized cooperation concept of environmental audit in various regions. Finally, a good audit environment should be created actively and the green development efficiency should be promoted by policy coordination. To give full play to the effectiveness of environmental governance supervision of environmental auditing to a maximum extent, policy coordination and work coordination should be strengthened from the perspective of national strategy, and the accuracy and intelligence of audit should be enhanced to provide a more ideal policy environment for environmental auditing.

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