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Technological Innovation, Fiscal Decentralization, Green Development Efficiency: Based on Spatial Effect and Moderating Effect

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Abstract: Green development efficiency is an essential measure of China's economy turning into a stage of high-quality development in the new era. This paper establishes a spatial Durbin model based on the new geography economics. It empirically investigates the spatial effect of technological innovation on regional green development efficiency and the moderating effect of fiscal decentralization on the above mechanism using panel data of 29 provinces in China from 2010 to 2018. The results show that: from 2010 to 2018, both technological innovation and green development efficiency in Chinese provinces show significant spatial clustering effects; technological innovation not only has a significant role in promoting green development efficiency in the region but also leads to the improvement of green development efficiency in neighboring regions; and fiscal decentralization positively regulates the direct effect of technological innovation on green development efficiency in the region, and negatively regulates the spatial spillover effect of technological innovation on green development efficiency in neighboring regions.

Keywords: fiscal decentralization; technological innovation; green development efficiency; spatial effect; moderating effect

1. Introduction

Since reform and opening up, China's industrialization and urbanization process has advanced rapidly, and China's economy has maintained a sustained and rapid growth, but the "high energy consumption, high emissions and high pollution" crude economic growth model has caused the growth of the total economic volume while consuming a large number of resources and causing serious resource and environmental problems, which has seriously restricted China's socio-economic high-quality development [1,2]. Compared with the traditional sloppy "black" development mode, green development promotes economic growth and environmental quality by improving energy utilization, reducing pollution emissions, and driving industrial transformation and upgrading, which is a "green" sustainable development mode. It has become an inevitable choice to escape from the dilemma of economic growth and ecological constraints and to achieve high-quality socio-economic development [3,4].

Green development emphasizes the coordination and unity of economic growth and environmental protection, and its focus is on the improvement of green development efficiency [4]. Green development efficiency is based on the efficiency of economic development, with more emphasis on resource input and environmental pollution, and is a crucial indicator of the level of regional green development [5]. Under the guidance of the new development concept, green development practices have been continuously promoted throughout China, but the overall level of green development in China still needs to be improved [6]. Therefore, exploring how to improve the efficiency of regional green development is a crucial step for China's economy to move towards the stage of

high-quality development. Innovation is the primary driver of development, and regional governments are trying to break the "economic production at the expense of ecological governance" in the industrialization process through innovative behavior. Technological innovation, as the core of innovation-driven high-quality development, can not only improve economic growth performance [7–10] but also effectively enhance the level of regional green development efficiencies, such as reducing energy consumption intensity [11,12], improving energy efficiency [13], and realizing waste recycling and pollutant emission management [14], thus effectively reconciling the contradictions between economy, society, and environment. Therefore, technological innovation is an effective way to improve the efficiency level of regional green development [15,16]. However, the process of technological innovation is usually accompanied by high costs and risks. For example, knowledge creation spillover effects usually make technological innovation activities have positive externalities, and technological innovation results have specific public goods properties, making the market fail in allocating technological factors and assigning technological value to them, which means that technological innovation must rely more on appropriate subsidies and interventions from local governments to compensate for market failures through institutional reforms and optimization [17–20]. Generally speaking, the performance of local government responsibilities is mainly influenced by a fiscal system centered on fiscal decentralization, which directly affects the efficiency of the supply of innovative public goods and determines the effectiveness of government support for technological innovation activities [21]. Therefore, fiscal decentralization is highly likely to impact regional green development by affecting the level of technological innovation [22]. However, fiscal decentralization has two sides: it gives local governments relatively flexible spending power, and growth-incentivized local governments will support technological innovation to achieve economic growth; on the other hand, technological innovation outcomes are often characterized by long lead times, high risks, and uncertainty, and local governments may lack incentives to invest in technological innovation due to self-interested investment preferences [18]. Therefore, clarifying whether fiscal decentralization plays a facilitating or inhibiting role in the relationship between the impact of technological innovation on the efficiency of green development is of great practical significance in enhancing the essential pillar role of finance in national governance, improving technological innovation, reducing environmental pollution and achieving green economic development.

In summary, the main question we want to examine is, under the guidance of the new development concept, what should regions do to improve the efficiency of regional green development? Is technological innovation an effective way to improve the efficiency of regional green development? Does fiscal decentralization play a facilitating or inhibiting role in the relationship between the impact of technological innovation on regional green development efficiency? In order to address these questions, this study empirically investigates the spatial spillover effects of technological innovation on regional green development efficiency and the moderating effect of fiscal decentralization on the above mechanism by developing a spatial Durbin model. The second section of this paper presents a review of the relevant literature. The third section introduces the theoretical basis and research hypotheses. The fourth section introduces the model selection, indicator selection, and data sources. The fifth section presents the results of the empirical analysis, and the sixth section gives the conclusions and recommendations and presents the limitations of this study.

2. Literature Review

Many scholars have researched technological innovation, fiscal decentralization, and green development efficiency. This paper has combed through the relevant literature and found that most of the studies mainly focus on three aspects: (1) research on regional green development efficiency measurement. Scholars have mainly applied Data Envelopment Analysis (DEA) [23–25], the Slacks-Based Measure model (SBM model) [26–30], and the super-efficiency SBM model [4,5], which consider multiple inputs and outputs, to measure the green development efficiency of cities and provinces. Wu et al. constructed a DEA

model to measure and analyze the green development efficiency of the Yangtze River Delta Urban Agglomerations and found that the green development gap between the three provinces and one city was narrowing year by year [23]; Zhou et al. measured the green development efficiency of Chinese cities based on the SBM model and found in their study that the green development of cities had a significant spillover effect [28]. In addition, since the DEA model does not take into account the slack variables, which may measure green development efficiency bias, and the SBM cannot rank multiple decision units with an efficiency value of 1, some scholars believe that it is more appropriate to use the super-efficient SBM model to measure green development efficiency [4,5]. (2) Regarding the research on the relationship between technological innovation and green development efficiency, there are two main opposing views: technological innovation can positively contribute to the efficiency of regional green development [3,16,30]. For example, Yuan et al. [3] combined the Directional Distance Function and SBM model to decompose the green development efficiency index into three parts: "change in technological innovation", "change in the technological gap", and "change in management efficiency". They found that technological innovation has a significant positive impact on green development through empirical analysis. Li et al. [2] used dynamic panel models and Systematic GMM methods. They found that energy-saving, emission reduction, and industrial upgrading effects were all effective transmission mechanisms for technological innovation to promote urban green development positively. The other view is that technological innovation may not be oriented towards green development and that there may be a 'rebound effect' [31,32]. In other words, technological innovation may stimulate economic growth and increase total energy demand, thus increasing resource consumption and pollution emissions in the production process, thus hindering the development of green transformation in the region. This "rebound effect" does not conflict with the energy-saving effect brought by technological innovation. Guo [33], when measuring the 'rebound effect' of energy consumption in China's industrial sector, points out that although the rebound effect of energy consumption in the industrial sector is much higher than that in developed countries, the overall improvement in energy efficiency in the industrial sector is still characterized by energy savings. (3) Regarding the relationship between fiscal decentralization and the efficiency of green development, scholars currently hold two main views: the theory of adverse effects. To achieve a GDP-focused promotion incentive assessment, local governments tend to focus more on short-term economic growth and neglect environmental management and resource conservation [17,34]. The fiscal decentralization systems induce the incentive for local governments to develop the economy at the expense of the environment, which will be detrimental to regional green development. Ran et al. [35] found through the spatial Durbin model that fiscal decentralization is not conducive to improving green development efficiency. Another view is the positive effect theory. For one, fiscal decentralization can improve the degrees of freedom of local governments in fiscal spending. For another, local governments can give full play to their information advantages and provide more appropriate innovative public goods and services according to local realities. These will be conducive to improving regional technological innovation and the efficiency of environmental governance. In addition, with the continuous socio-economic development, local governments have gradually changed from pursuing economic growth to pursuing synergistic development of economic growth and environmental protection, which further enhances the efficiency of regional green development [22,36]. Ren et al. [37] constructed a spatial econometric model with a panel data sample of 31 Chinese provinces from 2009–2018. They found a positive spatial spillover effect of fiscal decentralization on green economic development in the region.

Although the existing literature has laid a rich theoretical foundation for this study, there is still some room for expansion: firstly, the previous literature has mainly explored the impact of technological innovation on green development efficiency, the impact of fiscal decentralization on green development efficiency, and the impact of fiscal decentralization on technological innovation, and it is relatively rare to explore the impact of technological innovation on regional green development efficiency in the context of fiscal

decentralization; secondly, there are few scholars who have taken the institutional factor of fiscal decentralization as a moderating variable from the perspective of spatial spillover to study the influencing relationship between technological innovation and regional green development efficiency, and only consider the direct effect and ignore the spatial correlation between regions, which may cause the bias of research results. According to Tobler's first law of geography: "Everything is related, and the closer things are, the stronger the correlation" [38]; the economic activities of a region not only affect the economic development of the region but also affect the economic development of the surrounding regions, i.e., presenting a spatial spillover effect. China's development varies greatly and unevenly between regions, and the level of green development in different regions may show spatial clustering due to differences in the level of technological innovation and government fiscal expenditure [28]. Therefore, while exploring the relationship between technological innovation and regional green development efficiency in fiscal decentralization, it is also necessary to consider the spatial correlation between the variables. This paper uses a spatial Durbin model based on panel data of 29 Chinese provinces from 2010 to 2018, with fiscal decentralization as the moderating variable, to explore the "local-neighborhood" relationship between technological innovation and the level of regional green development efficiency.

3. Theoretical Analysis and Research Hypotheses

3.1. Technological Innovation and Green Development Efficiency

Technological innovation promotes the green development of the regional economy mainly through two ways: (1) improving the efficiency of energy conservation and emission reduction and driving industrial transformation and upgrading. By optimizing traditional production processes, technologies, and operation modes, technological innovation can cultivate resource recycling technologies and production pollution control technologies, which are conducive to reducing pollutants, waste, and energy consumption emitted in the production process and improving the efficiency of resource and energy use, thereby effectively enhancing the efficiency level of regional green development. From the perspective of energy conservation, technological innovation can effectively reduce energy consumption while non-energy factors and output levels remain unchanged, thus significantly improving energy use efficiency and promoting green development. Wang et al. [39] argue that enterprises with high innovation capabilities can improve energy use efficiency by improving existing energy technologies or developing new energy technologies, thus promoting green development; Li et al. [2], in their study of the relationship between technological innovation, energy-saving and urban green development, point out that companies that favor technological innovation in energy technologies will spontaneously reduce their energy demand or find new alternative energy sources, thus reducing energy consumption and promoting urban green development. At the same time, it is essential to note that when energy efficiency is improved, technological innovation may also stimulate economic growth and lead to an increase in total energy demand [31,32]. In practice, however, this 'rebound' effect does not conflict with the energy-saving effect of technological innovation, as the improvement in energy efficiency in the industrial sector is still characterized by energy savings [33]. From the perspective of emission reduction, technological innovation can promote green development by improving energy consumption structure. According to Fan et al. [40], improvements in energy consumption structure are a direct determinant of reducing carbon emission intensity, which can effectively reduce pollutant emissions while playing a positive role in promoting urban green development. In addition, the use of technological innovation to restructure the energy industry, the innovative use of green energy materials, and the improvement of their efficiency can make energy production environmentally friendly and give energy companies a competitive advantage [41–43]. For example, Borowski's research [41] points out that by using green materials such as bamboo to produce energy through eco-innovation techniques, energy companies can not only improve their energy profile and reduce their dependence on non-renewable energy sources but also reduce their polluting emissions, thus achieving the

goal of net-zero emissions. (2) Driving the transformation and upgrading of industries to "green." Technological innovation and its widespread application in social production are the technological basis for the green transformation of industries. Technological innovation promotes the development of traditional polluting industries into intelligent and green industries and helps to increase the proportion of low energy consumption, low pollution, and high value-added green industries in the industrial structure, and promotes the improvement of green development efficiency. Cha et al. [44] found that the optimization and upgrading of industrial structure can effectively improve carbon emission intensity, thus reducing overall pollution emissions and contributing to green economic development. In addition, everything is related, and the closer things are, the stronger the correlation. Technological innovation also has radiation diffusion and spatial spillover effects. For example, knowledge creation spillover effects usually make technological innovation activities, and technological innovation results have positive externalities. Based on the above analysis, this paper proposes Hypothesis 1 and Hypothesis 2:

Hypothesis 1. *From the direct effect, technological innovation in one region positively impacts the green development efficiency of the region.*

Hypothesis 2. *From the indirect effect, there is a positive spatial spillover effect of technological innovation in one region on the green development efficiency of neighboring regions.*

3.2. The Moderating Effect of Fiscal Decentralization

The fiscal decentralization system, which plays an essential function for local governments, plays an increasingly important role in innovation-driven development, and the constraints and incentives it constitutes have an essential impact on local technological innovation and green development [6]. In terms of incentives, as the pace of building an innovative country has accelerated in recent years, the central government has put forward some rigid requirements for local technological innovation, incorporating technological innovation performance into local government assessment indicators, so local governments are bound to promote economic growth through technological innovation in order to fulfil their assessment indicators, and local governments are more familiar with the development situation in their regions than the central government and are able to freely integrate resources within their jurisdictions according to the actual situation, making the allocation of resources in the innovation field more reasonable and effectively improving the efficiency of the use of resources, and ultimately realizing the growth of the local economy and the improvement of resource efficiency [17]. In their study on green R&D investment, fiscal decentralization, and regional carbon productivity, Li and Wang also point out that local governments with high fiscal decentralization also allocate sufficient funds to green R&D investment and environmental management for the sake of reputation evaluation [21]. Therefore, this paper argues that in the context of high fiscal decentralization, local governments will be more active in developing a green economy; in addition, when the degree of local fiscal decentralization increases, local government officials have the ability and incentive to pursue energy conservation, emission reduction, and industrial green transformation and development, and will set stricter local entry standards for enterprises, prompting enterprises in the region to move inefficient and energy-intensive production activities to neighboring regions. This phenomenon of "industrial relocation" will lead to an increase in pollutant emissions and a decrease in the efficiency of resource use in neighboring regions. At the same time, although the increase in local fiscal decentralization has led to increased support from local governments in the area of technological innovation, it will also lead to inter-regional competition for resources, making it more expensive for neighboring regions to obtain production resources, which is not conducive to green economic development in neighboring regions. Based on the above analysis, this paper proposes Hypothesis 3 and Hypothesis 4.

Hypothesis 3. *Fiscal decentralization positively moderates the direct effect of technological innovation on the efficiency of green development in adjacent areas.*

Hypothesis 4. *Fiscal decentralization negatively moderates the spatial spillover effects of technological innovation on the efficiency of green development in adjacent areas.*

4. Methodology and Materials

Previous studies have explored the relationship between technological innovation and green economic development, and fiscal decentralization and green economic development, respectively, from the perspective of spatial spillover effects. However, in the context of China's unique fiscal system, the relationship between the three is becoming closer and closer. It is vital to clarify the internal influence between the three. Therefore, to fully explore the impact of technological innovation on green economic development, this paper uses the moderated and spatial models to discuss the direct, indirect, and spatial spillover effects of technological innovation on green economic development and explores the critical role of fiscal decentralization. The specific research methods, index selection, data sources, and data processing methods are as follows.

4.1. Model Construction

According to Tobler [38]'s first law of geography, as mentioned earlier, the impact of technological innovation, fiscal decentralization, and green development efficiency may have spatial spillover effects. Hence, a spatial econometric model is necessary to analyze the impact of various variables on green development efficiency. By constructing a spatial econometric model, this paper explores the spatial correlation between technological innovation, fiscal decentralization, and regional green development efficiency. Elhorst [45] has proposed three types of spatial effect settings: spatial error model (SEM), spatial lag model (SLM), and spatial Durbin model (SDM). Among them, SLM refers to the inclusion of the spatial lag term of the explanatory variable in the general regression model, and SEM refers to the inclusion of the spatial lag term of the random error term in the general regression model. The SDM considers the spatial lag term of both the explanatory and explanatory variables and is the general form after combining SLM and SEM. Based on the research of Elhorst [45], this paper draws on the spatial panel model and constructs the SDM model as follows:

$$GDE_{it} = \alpha_0 + \rho WGDE_{it} + \beta_1 WTI_{it} + \beta_c WControl_{it} + \alpha_1 TI_{it} + \alpha_j WControl_{it} + u_i + \delta_t + \varepsilon_{it} \tag{1}$$

In Equation (1), GDE_{it} denotes the level of high-quality economic development in province *i* in period *t*, which indicates the level of digital economy development in province *i* in period t. The vector $Control_{it}$ denotes a set of control variables. u_i denotes the individual fixed effects of province *i* that do not vary over time, δ_t denotes the time-fixed effects, and ε_{it} denotes the random disturbance term.

In addition to the direct effect embodied in Equation (1), in order to further examine the moderating effect of fiscal decentralization on the relationship between technological innovation and green development efficiency, this paper constructs a model introducing the interaction term between fiscal decentralization and technological innovation based on model (2) above as follows:

$$GDE_{it} = \alpha_0 + \rho WGDE_{it} + \beta_1 WTI_{it} + \beta_2 WFD_{it} + \beta_3 W(TI*FD)_{it} + \beta_c WControl_{it} + \alpha_1 TI_{it} + \alpha_2 FD_{it}$$
$$+ \alpha_3 (TI*FD)_{it} + \alpha_j WControl_{it} + u_i + \delta_t + \varepsilon_{it} \tag{2}$$

In Equation (2), FD_{it} denotes the level of fiscal decentralization in province *i* in period *t*, while $(TI*FD)_{it}$ denotes the cross-cutting items of fiscal decentralization and technological innovation in province *i* in period $t \cdot \rho$ denotes the spatial autocorrelation coefficient of green development efficiency, and when $\rho > 0$, it means that green development efficiency of neighboring regions shows spatial spillover effect; when $\rho < 0$, it means that there is

a negative spatial effect between green development efficiency of neighboring regions. W denotes the spatial weight matrix.

The spatial weight matrix (W) is the key to performing the spatial correlation test. Due to space limitations, we chose a spatial distance matrix in this paper:

$$W_{ij} = \left\{ \begin{array}{l} {}^{1}/_{d_{ij}} \ , i \neq j \\ \quad 0 \end{array} \right. \tag{3}$$

In Equation (3), d_{ij} denotes the linear distance between province i and the capital city of province j.

The empirical analysis in this paper needs to be conducted based on testing whether there is a spatial correlation between technological innovation and green development efficiency. Therefore, this paper uses the spatial auto-correlation index Moran's I index to test the regional correlation and spatial dependence of technological innovation and green development efficiency in 29 provinces in China from 2010 to 2018. The expression of Moran's I index is as follows:

$$\text{Moran's I} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{S^2 \sum_{i=1}^{n}(x_i - \overline{x})^2} \tag{4}$$

In Equation (4), $\overline{x} = \frac{1}{n} \sum_{i=1}^{n}$, x_i and x_j denote the indicator values representing the provincial and provincial areas, n denotes the total number of provincial areas, and W_{ij} denotes the weight matrix, built based on different criteria, with a weight value of 1 if the two regions are adjacent or 0 if they are not.

$S^2 = \frac{\sum_{i=1}^{n}(x_i - x)^2}{n}$ denotes the sample variance. The value of Moran's I is between -1 and 1, which indicates a positive correlation of variables in adjacent regions when it is greater than 0, negative spatial correlation of variables when it is less than 0, and no spatial correlation between regions when it is equal to 0.

Unlike the classical regression model, the explanatory variables in the spatial Durbin model not only have a direct effect on the local green development efficiency but also have an indirect effect on the green development efficiency of adjacent regions. Therefore, a decomposition study of direct and indirect effects is needed. In this paper, drawing on the study of Pace and Lesage [46], the direct and indirect effects of the explanatory variables on green development efficiency in the spatial Durbin model are calculated through a partial differential approach as follows:

$$\left[\frac{\partial y}{\partial x_{1k}}, \frac{\partial y}{\partial x_{2k}}, \cdots, \frac{\partial y}{\partial x_{nk}} \right] = \begin{bmatrix} \frac{\partial y_1}{\partial x_{1k}} & \cdots & \frac{\partial y_1}{\partial x_{nk}} \\ \vdots & \vdots & \vdots \\ \frac{\partial y_n}{\partial x_{1k}} & \cdots & \frac{\partial y_n}{\partial x_{nk}} \end{bmatrix} = (I_n - \rho W)^{-1} \begin{bmatrix} \beta_k & w_{12}\theta_k & \cdots & w_{1n}\theta_k \\ w_{21}\theta_k & \beta_k & \cdots & w_{2n}\theta_k \\ \vdots & \vdots & \vdots & \vdots \\ w_{n1}\theta_k & w_{n2}\theta_k & \cdots & \beta_k \end{bmatrix} \tag{5}$$

In Equation (5), the mean of the diagonal elements' sum is the explanatory variable's direct effect on the explanatory variable. The mean of the sum of the non-diagonal elements is the indirect effect.

4.2. Measurement and Description of Variables

1.　　Explained variables: Green Development Efficiency

Green development efficiency is a measure of green development. The formula for measuring green development efficiency is shown below [2,47,48]. This paper uses the Super-SBM model containing non-desired outputs to construct evaluation indicators of green economic efficiency. Assuming K *(k = 1, … , K)* decision subjects, each using N *(n = 1, … , N)* inputs and producing M *(m = 1, … , M)* desired outputs and I *(i = 1,*

..., I) non-desired outputs with the jth in year t. The green economic efficiency (ρ_j^t) of the decision-maker is calculated as follows.

$$\rho_j^t = min \left[\frac{1 - \frac{1}{N} \sum_{n=1}^{N} \frac{s_{nt}^x}{x_{nt}^j}}{1 - \frac{1}{M+I} \left(\sum_{m=1}^{M} \frac{s_{mt}^y}{y_{mt}^j} + \sum_{i=1}^{I} \frac{s_{it}^b}{b_{it}^j} \right)} \right] \quad (6)$$

$$s.\ t.\ \sum_{k=1}^{K} z_k s_{nt}^m + s_{nt}^x = x_{nt}^j, n = 1, \ldots, N \quad (7)$$

$$\sum_{k=1}^{K} z_k y_{mt}^k - s_{mt}^y = y_{mt}^j, m = 1, \ldots, M \quad (8)$$

$$\sum_{k=1}^{K} z_k b_{it}^k + s_{it}^b = b_{it}^j, i = 1, \ldots, I \quad (9)$$

$$\sum_{k=1}^{K} z_k = 1 \quad (10)$$

$$z_k \geq 0,\ s_{nt}^x \geq 0,\ s_{mt}^y \geq 0,\ s_{it}^b \geq 0 \quad (11)$$

Green development efficiency reflects the input–output ratio in green development, which is the comprehensive utilization efficiency of the economy, resources, and ecological environment. It can represent the effectiveness of regional green development. In this paper, we adopt the Super-SBM model improved by Tone [49] and select provincial economic, environmental, and energy data to measure the green development efficiency of 29 provinces, setting capital stock, labor force and energy factor consumption as input variables, regional gross output value as desired output and industrial pollutant emission as the non-desired output. Among them, capital input is measured by capital stock, which is calculated by fixed asset formation according to the perpetual inventory method [50]. The depreciation rate is taken as 9.6%. The gross product of each province is obtained by deflating the actual value according to the consumer price index of each region, using 2010 as the base period. Table 1 shows the index system for measuring the efficiency of regional green development.

Table 1. Indicator system for measuring green development efficiency.

Indicators	Variables	Variable Definitions	Unit
Input indicators	Energy	Total energy consumption	per 10,000 tonnes of standard coal
	Labour	Number of people employed at the end of the year	per 10,000 people
	Capital	Capital stock	RMB per 100 million yuan
OutputsIndicators	Desired output — GDP	Real GDP	RMB per 100 million yuan
	Non-desired outputs	Environmental pollution	Industrial sulfur dioxide emissions — per million tons Industrial wastewater discharge — per 10,000 tons Industrial smoke (dust) emissions — per 10,000 tons

2. Explanatory variables: technological innovation

The core explanatory variable of this paper is technological innovation, which is measured by using R&D investment intensity by provinces and cities and is calculated by using R&D expenditure/GDP of industrial enterprises above the size of each province, drawing on Wu [51].

3. Moderating variables: fiscal decentralization

Government fiscal expenditure and its size are directly related to the level of science and technology and the degree of innovation and further influence the government functions in the regional innovation system. This paper draws on Qi Yu et al. [52] to measure

fiscal decentralization using the ratio of provincial fiscal budget expenditures to major fiscal budget expenditures. The expression of fiscal decentralization is as follows:

$$FD = \frac{\text{Provincial fiscal budget expenditure}}{\text{Central fiscal budget expenditure}} \tag{12}$$

4. Control variables.

Considering that the efficiency of green development may also be affected by other variables, based on the existing literature, this paper adds gross domestic product per capita (GDP per capita), industrial structure level (IS), and energy consumption structure (ECS) as control variables in the above spatial econometric model, using the natural logarithm of real gross domestic product per capita, the ratio of secondary industry to GDP and coal consumption to total energy consumption, respectively.

4.3. Data Sources and Descriptive Statistics

In view of the continuity and availability of data, this paper is measured and analyzed with the panel data of 29 provinces in China's mainland from 2010 to 2018, except for Tibet and Hainan. The relevant data of the selected research variables are obtained from the China Statistical Yearbook, China Science and Technology Statistical Yearbook, China Energy Statistical Yearbook, China Industrial Statistical Yearbook, China Finance Yearbook, and the statistical yearbooks of each province in the relevant years. The descriptive statistical results of the relevant variables are shown in Table 2.

Table 2. Results of descriptive statistics for each variable.

Variable Name	Average Value	Standard Deviation	Maximum Value	Minimum Value	Number of Samples
Green Development Efficiency	0.8340	0.1443	1.2781	0.5241	261
Technological innovation	0.1624	0.1104	0.6170	0.0480	261
Financial decentralization	0.0280	0.0131	0.0740	0.0057	261
The logarithm of GDP per capita	2.4719	1.3318	6.6658	0.6915	261
Industrial structure	0.4911	0.0530	0.6148	0.3181	261
Energy consumption structure	4.1174	0.5029	5.0300	1.5900	261

5. Empirical Results of the Models

5.1. Analysis of Spatial Auto-Correlation Results

In this paper, the Moran's I indices of regional technological innovation and green development efficiency from 2010–2018 were calculated according to the above Moran's I index expressions, respectively. The results are shown in Table 3. As can be seen from Table 3, the Moran's I indices of technological innovation and green development efficiency from 2010–2018 are greater than zero and pass the 5% significance test, which indicates that technological innovation and green development efficiency have a significant positive spatial correlation in the spatial range and have a spatial agglomeration effect. Therefore, the spatial effect should be considered when constructing the impact model of technological innovation and green development efficiency to be consistent with the facts.

Table 3. Table of Moran's I indices of technological innovation and green development efficiency.

Variables	Year	2010	2011	2012	2013	2014	2015	2016	2017	2018
GDE	Moran's I	0.132	0.160	0.187	0.199	0.214	0.228	0.230	0.239	0.239
	Z-value	1.881	2.112	2.352	2.415	2.535	2.652	2.648	2.700	2.739
	p-value	0.030	0.017	0.009	0.008	0.006	0.004	0.004	0.003	0.003
TI	Moran's I	0.279	0.262	0.285	0.254	0.246	0.232	0.276	0.259	0.274
	Z-value	2.837	2.688	2.889	2.613	2.537	2.412	2.806	2.661	2.792
	p-value	0.002	0.004	0.002	0.004	0.006	0.008	0.003	0.004	0.003

5.2. Selection of Model and Estimation Methods

In order to correctly estimate the relationship between technological innovation, fiscal decentralization, and green development efficiency, this study needs to select the most appropriate spatial panel econometric model for parameter estimation. The specific selection process can be divided into two steps: (1) Using the LM test and robust LM test to judge the selection of SLM and SEM models, and if both are appropriate, the more general SDM model is introduced. (2) In order to judge whether the spatial Durbin model can be reduced to a spatial error model and a spatial lag model, it is estimated by LR test in this paper, and the results are shown in Table 4.

Table 4. LM, robust LM tests and likelihood ratio (LR) tests.

		LM Test		Robust LM Test		LR Test	
		Z-Value	*p*-Value	Z-Value	*p*-Value	Z-Value	*p*-Value
Unregulated variables	SLM	7.417	0.006	10.885	0.001	25.670	0.000
	SEM	46.781	0.000	50.248	0.000	55.260	0.000
Adding moderating variables	SLM	92.204	0.000	2.713	0.100	29.460	0.000
	SEM	152.646	0.000	63.155	0.000	59.010	0.000

From the results of the LM test, robust LM test, and LR test in Table 4, it can be seen that the LM test and robust LM test of both SLM and SEM are significant at the 10% level when no moderating variables are added, which indicates that both control correlation terms and spatial error terms exist in the set models. Therefore, the SDM is the most appropriate model for estimating the relationship between technological innovation and green development efficiency. Therefore, the SDM is the most appropriate model to estimate the relationship between technological innovation and green development efficiency. In addition, the test results of this study with the addition of moderating variables are the same as above, so the SDM is also chosen in this paper to explore the effect of fiscal decentralization on the mechanism of technological innovation and green development efficiency.

5.3. Analysis of Regression Results

This paper regresses the model of technological innovation and green development efficiency to first explore the relationship between technological innovation and green development efficiency in the absence of moderating variables, and then introduces fiscal decentralization as a moderating variable to explore the impact of the interaction term between fiscal decentralization and technological innovation on green development efficiency. Before conducting the regression estimation, since it is necessary to determine whether to choose random effects or fixed effects as the basic model of this paper, the relationship between spatial effects and explanatory variables is analyzed by the Hausman test. The results show that the Hausman test is negative both when there are no moderating variables and when moderating variables are added, which indicates that the hypothesis that the disturbance term of the random effect is not correlated with the explanatory variables is not satisfied and the random effect is rejected, so the fixed effect model should be selected in both cases [53].

5.3.1. Technological Innovation and Green Development Efficiency

The regression results of the OLS model of technological innovation and green development efficiency and the regression results of the spatial Durbin model are shown in Table 5. As can be seen from Table 5: (1) The coefficient of W*GDE is significantly positive, which indicates that China's green development efficiency has a positive spatial spillover effect, and regions with high green development efficiency will lead to the improvement of green development efficiency in neighboring provinces. (2) The coefficient of technological innovation on green development efficiency is positive and significant at the 1% level, indicating that technological innovation has a significant role in promoting regional green

development efficiency, which indicates that enhancing regional technological innovation capacity can improve energy use efficiency and pollution control capacity through intensive development and kinetic energy optimization, and finally improve regional green development efficiency. (3) Among the control variables, energy consumption structure (ECS) has a significant negative effect on green development efficiency. Thus, it can be seen that the coal-based energy consumption structure is detrimental to energy efficiency improvement and technological progress and brings about a sharp increase in pollutant emissions, which leads to the reduction in green development efficiency.

Table 5. Spatial Durbin model measurement results.

Variables	OLS	SDM
C	1.4322	0.48
TI	0.5701 ***	0.4862 ***
LnGDP per capita	−0.0245 ***	−0.0313 ***
IS	0.1225	−0.0877
ECS	−0.1679 ***	−0.1371 ***
$W * TI$	–	0.3506 *
$W * LnGDP$ per capita	–	0.0102
$W * IS$	–	0.1214
$W * ECS$	–	−0.0302
$W * GDE$	–	0.1299 *
R^2	0.6124	0.6984
$\log L$	–	302.4783

Note: ***, **, * indicate the estimated coefficients are significant at the 1%, 5%, and 10% levels, respectively.

In order to further investigate the mechanism of action and spatial spillover effects between technological innovation and green development efficiency, this paper uses the spatial Durbin model and decomposes the spatial effects of the research subjects using the partial differential matrix method, and analyzes their direct, indirect and total effects. Table 6 shows the results of the decomposition of direct and indirect effects of the spatial Durbin model. From Table 6, it can be seen that the coefficients of both direct and indirect effects of technological innovation are significantly positive at the 1% level, which indicates that technological innovation can not only promote the green development efficiency of the region but also have a driving effect on the green development efficiency of neighboring regions. This phenomenon may arise due to the diffusion effect brought about by the improvement of technology level. The local production factors will spill over to the neighboring regions and have a radiating effect on the neighboring regions, which makes the neighboring regions continuously carry out technological innovation and optimize resource allocation to expand economic output, thus improving the green development efficiency of the neighboring regions, which is consistent with the conjecture of Hypothesis 1 and Hypothesis 2.

Table 6. Decomposition of effects for the spatial Durbin model.

Variables	Direct Effects	Indirect Effects	Total Effect
TI	0.5043 ***	0.4890 ***	0.9934 ***
LnGDP per capita	−0.0308 ***	0.0055	−0.2532
IS	−0.0879	0.1379	0.0499
ECS	−0.1385 ***	−0.6020 *	−0.19865 ***

Note: ***, **, * indicate the estimated coefficients are significant at the 1%, 5%, and 10% levels, respectively.

5.3.2. Relationship between Technological Innovation and Green Development Efficiency under Fiscal Decentralization

Table 7 shows the estimation results of the spatial Durbin model with fiscal decentralization as the moderating variable. It can be found that (1) the coefficient of the interaction

term between technological innovation and fiscal decentralization is positive and significant at the 5% significance level, indicating that fiscal decentralization can significantly enhance the positive relationship between technological innovation and green development efficiency; (2) the coefficient of W*GDE is still significantly positive, which again proves that green development efficiency in China has a positive spatial spillover effect.

Table 7. Estimation results of the spatial Durbin model with fiscal decentralization as a moderating variable.

Variables	OLS	SDM
C	1.4089	–
TI	0.6388 ***	0.4982 ***
TI * FD	−0.0213	0.3541 **
LnGDP per capita	−0.02727 ***	−0.3333 ***
IS	0.1159	−0.1145
ECS	−0.1621 ***	−0.4156 ***
W * TI	–	0.2511
W * TI * FD	–	−1.0040 *
W * LnGDP per capita	–	0.0241
W * IS	–	−0.1974
W * ECS	–	−0.0335 **
W * GDE	–	0.1424 *
R^2	0.6207	0.6883
log L	–	305.7194

Note: ***, **, * indicate the estimated coefficients are significant at the 1%, 5%, and 10% levels, respectively.

To further explore the moderating effect of fiscal decentralization, this paper decomposes it into direct and indirect effects, and the results are shown in Table 8. It can be found that: (1) the direct and indirect effects of technological innovation and green development efficiency are significantly positive at a 10% significance level. (2) The direct effect of the interaction term between fiscal decentralization and technological innovation is significantly positive, which indicates that fiscal decentralization can significantly enhance the role of intra-regional technological innovation in promoting regional green development efficiency. Therefore, Hypothesis 3 holds; that is, regional governments with high fiscal decentralization not only have more sufficient funds to support innovation development but also can freely integrate resources within their jurisdictions to improve technological innovation and energy utilization according to the actual situation, thus realizing the purpose of changing the local economic growth model and improving the regional environmental quality, and finally enhancing the efficiency of local green development. (3) The indirect effect of the interaction term between fiscal decentralization and technological innovation is significantly negative, indicating that fiscal decentralization has an inhibitory effect on local technological innovation leading to the improvement of green development efficiency in neighboring regions. It can be seen that Hypothesis 4 is valid; that is, higher local fiscal decentralization will lead to "industrial locational reset" and vicious competition for innovation resources, which will negatively impact the green development efficiency of neighboring regions.

Table 8. Direct and indirect effects of the spatial Durbin model with fiscal decentralization as a moderating variable.

Variables	Direct Effects	Indirect Effects	Total Effect
TI	0.5121 ***	0.3737 *	0.8858 ***
TI * FD	0.3351 **	−0.4065 *	−0.0714
LnGDP per capita	−0.328 ***	0.02196	−0.0109
IS	−0.1118	−0.2420	−0.3538
ECS	−0.1369 ***	−0.0571	−0.1931 ***

Note: ***, **, * indicate the estimated coefficients are significant at the 1%, 5%, and 10% levels, respectively.

6. Conclusions and Policy Recommendations

This paper explores the relationship between fiscal decentralization, technological innovation, and green development efficiency by establishing a spatial Durbin model based on new geography economics. It is found that: (1) technological innovation and green development efficiency both show significant spatial agglomeration effects; technological innovation not only has a significant role in promoting green development efficiency in the region, but also leads to the improvement of green development efficiency in neighboring regions; (2) from the perspective of spatial spillover, this study investigates the regulation effect of fiscal decentralization on the relationship between technological innovation and green development efficiency, and finds that fiscal decentralization can positively moderate the effect of technological innovation on green development efficiency. (3) By studying the moderating effect of fiscal decentralization on the relationship between technological innovation and green development efficiency, this study finds that fiscal decentralization positively regulates the direct effect of technological innovation on green development efficiency in the region, while it negatively regulates the spatial spillover effect of technological innovation on green development efficiency in neighboring regions. Based on the above findings, this paper proposes the following countermeasures.

(1) In terms of technological innovation. ①Technological innovation is an effective driver of green development. In this regard, the government should establish and improve the innovation system, reduce the obstructive factors to enterprise innovation, increase the support to the innovation field, improve technology incubation, scientific and technological research and development and the market of technological achievements, and promote the economic structure to green and low-carbon development; meanwhile, the government should also formulate industrial policies to encourage innovation, drive the traditional polluting industries to intelligent and green development, and increase the share of low energy consumption, low pollution and high value-added green industries in the industry. At the same time, the government should also formulate industrial policies to encourage innovation and drive traditional polluting industries to develop in an intelligent and greenway, increase the proportion of low energy consumption, low pollution, and high value-added green industries in the industrial structure, and promote the efficiency of regional green development. ②In the process of implementing technological innovation to drive regional development efficiency, local governments should take into account the actual economic development status and innovation level of the region and implement differentiated policies. Suppose the eastern coastal region has a higher level of green development efficiency. In that case, the government should continuously stimulate the spillover effect of green development efficiency and improve the guiding demonstration role for the central and western regions. The central and western regions, on the other hand, need to strengthen the management mechanism of energy-intensive industries with low output, high energy consumption, and high pollution and also increase the support for technological innovation to promote the green transformation and upgrading of industries.

(2) In terms of fiscal decentralization, ① the fiscal decentralization system has a significant role in promoting the efficiency of green development. The central government should continue to decentralize part of its financial power, give localities a higher degree of financial autonomy, and make full use of the information advantages of local governments so as to optimize the efficiency of resource allocation. ②The central government needs to make appropriate adjustments to the performance appraisal methods of local governments in light of the actual situation. In the performance appraisal system of local governments, technological innovation and environmental quality should be added to the "GDP-only" appraisal method to motivate local governments to develop a green economy and technological innovation to promote the improvement of green development efficiency in China. ③ In order to reduce the negative impact of financial decentralization of neighboring regions on the green

development efficiency of the region, each region should take into full consideration its own resource advantages and endowments when formulating green development strategies, formulate policies suitable for the green development of the region in a targeted manner, promote the free circulation of green production factors among regions through fair competition and win–win cooperation among regions, and improve the level of technological innovation and green economic resource allocation to ensure the efficiency of the region. The green production factors are promoted to circulate freely among regions through reasonable competition and win–win cooperation among regions. The level of technological innovation and green economic resource allocation is improved to ensure the stability of green development in the region.

Green development efficiency also reflects the development of social systems. This study only considers the pursuit of economic benefits and environmental pollution control from two perspectives, ignoring that human social activities also generate social benefits and pollutants. In subsequent studies, the influence of social factors can be taken into account in the evaluation of green development efficiency by considering breaking the traditional "black box" model and dividing the provincial green development efficiency evaluation system into a two-stage, three-system network structure, and separately considering the green development efficiency of the economic and social benefit subsystems, so that the real root causes of inefficient green development can be found and have stronger practicality.

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