

# Does Green Finance Promote Green Technology Innovation in China

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**Abstract:** This paper selects the panel data of 30 provinces in China from 2008-2019 (due to the lack of data in some regions, this paper excludes the data of Tibet, Hong Kong, Macao and Taiwan), uses data envelopment analysis to calculate the level of green technology innovation in China, and constructs a spatial Dubin model on this basis to explore whether the development of green finance can promote the improvement of the level of green technology innovation in China. The empirical analysis shows that: first, green finance will promote the improvement of the level of green technology innovation in the region; Secondly, green finance does have a spatial spillover effect on green technology innovation, and the development of green finance in this region will restrain the development of green technology innovation in neighboring areas to a certain extent.

**Keywords:** Green finance, Green technology innovation, Spatial Dubin model.

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## 1. Introduction

Since the reform and opening up, China's economy has developed rapidly and made remarkable achievements, and China has become the second largest economy in the world. But at the same time, problems such as environmental degradation, serious loss of resources and impact on ecological balance have also followed, and the shortcomings of the traditional extensive development mode have gradually been exposed, which seriously challenges the carrying capacity of the environment. In this case, it is particularly important to promote the green transformation of development mode. The 14th five year plan and the long-term goal of 2035 clearly put forward that we should "promote the comprehensive green transformation of economic and social development and build a beautiful China". In the report of the 20th National Congress of the Communist Party of China, it is further emphasized that "promoting green and low-carbon economic and social development is the key link to achieve high-quality development." in the process of promoting green transformation, it is inseparable from the support of technology. Technological progress is seen as one of the important means to reduce environmental pollution and can play a role in reducing emissions and promoting growth, especially when technological progress is more biased towards energy conservation [1]. Of course, the green transformation of the economy will inevitably be accompanied by the flow of capital and factors among various industrial sectors, which requires strong support from the financial sector [2]. In the process of green transformation, if green technology is the premise and path, then green finance is an important means, the main purpose is to serve green technology innovation.

Scholars have long paid attention to the relationship between green finance and green technology. Some scholars believe that green finance can guide more funds to green and clean industries by reallocating credit resources, which can not only promote the development of green industries, but also force polluting enterprises to carry out green transformation [3]. In addition to resource allocation, green financial policy can also play a role in risk management and control, and help enterprises open up the market and establish

competitive advantages [4]. Compared with traditional finance, green finance can affect the capital chain of high polluting and high consuming enterprises by adjusting interest rates and strengthening supervision, increase their financing costs, and thus force them to carry out green technological innovation [5]. At the same time, diversified green financial products and supporting systems can also help improve the efficiency of green technology innovation [6]. However, some scholars hold different opinions. They believe that China's green finance is still in its infancy, its development is not yet mature, and its relationship with green technology innovation has not reached a state of mutual promotion and support [7, 8]. Moreover, the industrial chain and capital chain between green capital and green technology lack financing channels, and the supply and demand of funds are difficult to balance well [9, 10]. These are the issues that many scholars are concerned about at present, and have made corresponding discussions and studies from different angles, but there are fewer comparative studies on the direct impact of green finance on green technology innovation, especially on the progress of biased technology and technology. Therefore, this paper focuses more on this issue to provide more research ideas for studying the impact of green finance on green technology innovation.

## 2. Literature Review

### 2.1. Green finance

The theory of green finance was first born in the 1970s, but there is no consensus in academia on the definition of the concept of green finance. Some early scholars described green finance as "environmental finance" or "sustainable finance" [11]. Unlike traditional finance, the emergence of green finance aims to promote environmental protection and achieve sustainable economic development [12], and it pays more attention to the coordinated development of financial activities with environmental protection and ecological balance. Labatt et al. [13] further pointed out in their research that green finance, as a new financial means, can effectively control and reduce the risk of environmental pollution, thus improving the quality of the ecological environment. At the same time, the development of green financial business itself

plays a positive role in the financial industry and financial institutions, and the ability of financial institutions to control and resist risks will be further improved [14]. With the concept of green transformation and low-carbon development gradually becoming a consensus in China, more and more scholars in China pay attention to the field of green finance. He [15] studied and defined green finance earlier in China, put forward that green finance policy refers to the policy of giving priority to supporting green industries from the flow of credit funds and interest rates. Since then, many scholars have put forward some views on the concept of green finance, and the guiding opinions on building a green financial system issued by the people's Bank of China and other seven ministries and commissions in 2016 formally defined the connotation of green finance. Many scholars have analyzed the role and value function of green finance in the national economy from different perspectives. From the macro level, Yu and fan [16] found that green finance has a significant role in promoting the high-quality development of regional economy through empirical analysis of the data of 30 provinces (cities, autonomous regions) in China from 2009 to 2019. Gou and Lu [17] also believe that green finance can promote the high-quality development of regional economy from direct and indirect channels. Zhang et al. [18] believe that green finance can significantly promote the optimization of industrial structure. Ma and Yu [19] found in their research that green investment can provide impetus for sustainable economic development by promoting the development of green industries. At the micro level, Wang [20] said that the risk taking level of environmental protection companies will inhibit the innovation performance of enterprises, but green finance can significantly improve the innovation performance of enterprises. When Lei and Shi [21] analyzed the impact of green credit on commercial banks, they found that green credit can not only improve the performance level of banks, but also improve the risk control ability of banks. Wang and Li [22] pointed out that environmental and climate risks have had a new impact on the stable operation of the economic and financial system, and the development of green finance can provide new ideas for preventing and resolving systemic financial risks.

## 2.2. Green technology innovation

The concept of green technology innovation originates from the idea of green technology put forward by Braun and wield [23], which means a technology that can save the use of resources, reduce the input of raw materials, and protect the ecological environment on this basis. There is no unified academic definition of the term green innovation. Tao et al. [24] defined it as an activity that uses new knowledge of environmental protection and green technology in production and operation to create and realize new economic benefits and environmental values, that is to say, it is oriented by the green market to promote the transformation of green technology achievements. The European Commission's definition of green technology innovation is to follow the ecological principles and ecological economic laws, save resources and energy, avoid, eliminate or reduce the pollution and destruction of the ecological environment, and the general term of "pollution free" or "less pollution" technologies, industries and products with the smallest negative ecological effects. Some scholars have also discussed the connotation and process of green technology innovation. Based on the difference in the degree of technological evolution and the

difficulty of matching the existing selection environment, Yang and Lv [25] divided green technological innovation into three levels: terminal governance technological innovation, green process innovation and green product innovation. Wang et al. [26] divided enterprise technological innovation strategies into four types: passive strategy, participatory strategy, active strategy and innovative strategy on the basis of the differences in innovation opportunities provided by the industrial sector and the potential change trend of the market. For the green process of innovation sources, Li [27] divided many green technology development categories into four levels of green technology innovation system: the participation of government, universities and enterprises; Cooperation between universities and enterprises; Independent development by enterprises or universities; Enterprises transform traditional products. It emphasizes the joint role of individual subjects in enterprises in order to solve the external economic problems of green technology innovation and realize the values of sustainable development.

## 2.3. Green finance and green technology innovation

According to the existing research, the role of green finance in green technology innovation is divided into promotion theory and suppression theory: some scholars believe that green finance can guide social capital to green environmental protection enterprises and provide financial support for new green technology research and development, so as to achieve the purpose of promoting green technology innovation; Other scholars believe that green finance restricts the development of high polluting and high-energy consuming enterprises by shrinking funds and other measures, but also inhibits the funds used by these enterprises to invest in research and development of new technologies.

In the relevant research that green finance will promote green technology innovation, according to its mechanism, it can be divided into two aspects: strengthening the diversification of green financial system and improving the efficiency of green financial institutions. Scholars have shown that compared with a single green financial system, a diversified green financial system can provide more effective financial support. The empirical research of Woo et al. [28] showed that the diversified green financial system with green stock market, fund market and bond market can improve the level of green technology innovation better than the single green financial system. Dong et al. [29] found that financial scale, financial structure and financial efficiency have a positive impact on green technology innovation, but the impact of financial scale is the smallest, that is to say, in the process of green enterprise development, we should pay attention to the optimization of financial structure and the improvement of financial efficiency. At the same time, scholars believe that improving the efficiency of green finance can better promote green technology innovation. Jacob h. [30] found through empirical research that the efficiency improvement of green financial institutions can drive a series of social capital into energy conservation and environmental protection industries, thus shortening the financing cycle of the above enterprises and providing financial guarantee for the technological innovation of green enterprises. Cao [31] found that the financing channels of green enterprises in central and eastern China are mainly social capital, while the western region is fiscal investment, and the structural efficiency of green finance in the western

region is significantly lower than that in the eastern and central regions. It is concluded that improving the efficiency of green financial structure in the western region can narrow the development gap between the western region and the central and eastern regions. However, some scholars hold different views, and they believe that green finance may have a negative impact on green technology innovation. Sun et al. [32] found that due to the large development gap between China's green financial system and green technological innovation system, it is difficult to form a situation of mutual promotion, and there is a problem of structural imbalance within the green financial system. Mark et al. [33] found that the Asian Development Bank will take into account the pollution of enterprises when granting loans, that is, the environmental performance of enterprises will be included in the assessment criteria of whether to grant loans, which greatly reduces the credit amount of highly polluting and energy-consuming enterprises. Gu [34] also confirmed the above view, pointing out that although green credit does have a significant effect on restricting the credit amount of high-energy consuming enterprises, it will also further hinder the development of green technology innovation activities by these enterprises due to the lack of funds for R&D. Wang's [35] research showed that the profit margin of unit products in highly polluting industries is low. Under the carbon financial system, enterprises need to pay a high fee to purchase carbon emission rights every year, which crowds out the liquidity of enterprises for green technology research and development, and further hinders green technology innovation by high-energy consumption and high pollution enterprises.

To sum up, the literature on green finance at home and abroad provides a valuable reference for follow-up research, but most of the existing literature focuses on the impact of green finance on green technology innovation, or focuses on the single dimension of green finance, such as the carbon reduction effect of green credit, and there are relatively few studies to comprehensively evaluate the impact of green finance development on the efficiency of green technology innovation. The possible marginal contributions of this paper are as follows: first, this paper combs and draws lessons from the views, indicators and methods of green financial development evaluation research at home and abroad, and combines the information disclosure and statistical characteristics of green finance in China to analyze the impact of green finance on green technology innovation more comprehensively and comprehensively; Secondly, considering the efficiency of green technology innovation, we should examine whether the development of green finance can promote the efficiency of green technology innovation; Thirdly, using the spatial econometrics model, this paper explores whether there is a spatial spillover effect of green finance on regional green technology innovation.

### **3. Mechanism Analysis**

#### **3.1. Basic functions of green finance to promote green technology innovation**

Early neoclassical economic theory believed that environmental protection policies would increase the production cost of enterprises and reduce the R&D funds of enterprises, which was not conducive to enterprise innovation and productivity improvement. However, Porter [36] put forward the Porter hypothesis, which is opposite to his view.

He believes that appropriate environmental protection policies can force enterprise producers to invest more money in technology research and development, so as to achieve green technology innovation and reduce environmental pollution. As an extension of traditional finance, green finance also has the functions of resource allocation, capital aggregation and risk control. The capital allocation function of green finance allocates regional human, capital and technology resources more reasonably, and then transfers them to green industries, so as to improve the efficiency of innovation and R&D of green industries and further promote the development level of regional green technology innovation. The main body of green technology innovation is the green industry within the region, and green finance can help the green industry broaden financing channels and break through the restrictions of capital bottlenecks. Through the operation of green financial instruments such as green credit and green insurance, the financing of high pollution and high consumption industries is restricted, and the idle funds in society are gathered and reallocated to the green industries in the region. After the green industry achieves innovative output, through the operation of green financial instruments, innovative achievements can be transformed into capital in the capital market. While the application of green technology brings high returns, there are also huge risks in its innovation process. Green industry projects need a lot of funds for green technology research and development in the early stage, and the cycle of project research is also uncertain, usually with a long time span. Faced with this situation, green finance can control and disperse risks through professional operation mechanism. On the one hand, the perfect information disclosure mechanism established by green finance can provide real information for investors in related industries more conveniently and efficiently, so that investors can obtain and process related investment information at a lower cost; On the other hand, the green financial market will transform the innovative achievements of green technology into asset pools, so as to realize the securitization operation of innovative output, so as to disperse and transfer the risks borne by green industry in the process of green technology research and development.

#### **3.2. Spatial spillover effect of Green Finance on regional green technology innovation**

There will be some differences in the level of economic development in various regions. Similarly, there are also such differences in the level of human capital and the distribution of financial resources, and green finance tends to play different roles in different stages, and the impact of different regions on this region and neighboring regions is also different. Generally speaking, areas with a higher level of green financial development tend to produce a "siphon effect", attract more talents, capital and other resources to gather themselves, and provide more human resources and financial support for technological innovation and R&D in the region, so as to enhance the level of green technological innovation in the region. However, when the green finance in the region develops to a certain level, the excessive accumulation of resources will begin to withdraw from the market in the region due to fierce competition and other reasons, and slowly transfer to the surrounding areas, thus driving the improvement of the level of green technology innovation in the surrounding areas. At the same time, neighboring areas will also actively introduce talents from areas with higher

levels of green financial development, invest in technology research and development and the development of green industries, and realize the upgrading of technology and the improvement of innovation ability in the region. To sum up, while promoting green technology innovation in the region, green finance in the region will also have an impact on the level of green technology innovation in neighboring areas.

Based on the above analysis, we propose the following assumptions:

Hypothesis 1: green finance can promote the level of green technology innovation in the region.

Hypothesis 2: green finance has a spatial spillover effect on the level of green technology innovation in the region, and will promote the level of green technology innovation in neighboring regions.

## 4. Model Setting and Variable Selection

### 4.1. Model setting

This paper mainly discusses the impact of green finance on green technology innovation. Because green finance has a certain spatial agglomeration, space factors are added to the research process. As a general form of spatial autoregressive model and spatial error model, spatial Dubin model can more comprehensively reflect the spatial spillover effect of green finance on green technological innovation, so it is selected as a benchmark model for analysis. The following will also carry out relevant tests to further verify the rationality of the model. The specific models are as follows:

$$GTI_{it} = \alpha_0 + \rho\omega GTI_{it} + \beta_j x_{it} + \gamma_j \omega x_{it} + \mu_i + v_i + \varepsilon_{it}$$

Among them, I represents the i-th region, T represents the

T-Year,  $\mu_i$  represents the spatial fixed effect,  $v_i$  represents the time fixed effect,  $\varepsilon_{it}$  represents the random error term, and  $\omega$  is the spatial weight term. GTI refers to the level of green technological innovation, which is mainly measured by the efficiency of green technological innovation, including energy biased technological progress ee, pollution control technological progress pa, backup technological progress bt, X as explanatory variables, including core explanatory variables green finance GF and various control variables. The control variables refer to the existing research in related fields, and the following variables are selected: foreign direct investment level fdi, environmental regulation er, per capita GDP, Openness level open, R&D investment RD, per capita education level edu and the square of per capita GDP.

### 4.2. Variable selection

Explained variable: green technology innovation. At present, most of the existing studies measure the level of green technology innovation from two aspects, one is the number of green patent applications, the other is to calculate the efficiency of green technology innovation. Referring to the practice of Yan et al. [37], this paper uses data envelopment analysis (DEA) to calculate the innovation efficiency, and represents the level of green technology innovation. The three types of efficiency calculated by DEA, namely, non fossil energy efficiency, fossil energy efficiency and environmental efficiency, represent reserve technological progress, energy biased technological progress and pollution control technological progress respectively.

Core explanatory variable: green finance. Referring to the practice of Lv et al. [38], this paper constructs the evaluation system of green finance from the four dimensions of green credit, green investment, green insurance and government support, and uses entropy method to calculate.

**Table 1.** Evaluation System of green financial development level

Primary indicators	Secondary indicators	Index definition	Index nature
Green credit	Proportion of high energy consumption interest expenditure	Six high energy consuming industrial interest expenditure/total industrial interest expenditure	Negative
Green investments	Proportion of pollution control investment	Pollution control investment/GDP	Positive
Green insurance	Depth of agricultural insurance	Agricultural insurance income/total agricultural output value	Positive
Government support	Proportion of fiscal and environmental protection expenditure	Fiscal environmental protection expenditure/fiscal general budget expenditure	Negative

Control variables: referring to the existing research on the level of green technology innovation, the level of foreign direct investment (fdi) is selected and measured by the ratio of foreign direct investment to GDP; Environmental regulation (er) is measured by the ratio of industrial pollution control investment to the secondary industry; Gross domestic product per capita (gdpc), measured as a ratio of gross domestic product to total population; Openness (open), measured as a ratio of total imports and exports to gross domestic product; R&D investment (RD), measured as a ratio of R&D investment to GDP; Per capita education level (edu), measured by per capita years of education; The square of GDP per capita is used as the control variable.

### 4.3. Setting of spatial weight matrix

Referring to the existing research in related fields, this paper selects the geographic distance matrix as the spatial weight matrix, and standardizes the matrix. The specific calculation formula is as follows:

$$w_{ij} = \frac{1}{d_{ij}}$$

Among them,  $d_{ij}$  is the geographical distance calculated according to the longitude and latitude of the two places. The meanings and descriptive statistics of the main variables involved in this paper are shown in Table 2:

**Table 2.** Variable meaning and descriptive statistics

Variable	Symbol	Definition	Observations	Mean value	Standard deviation	Min	Max
Energy biased technological progress	ee1	Fossil energy efficiency	360	0.555	0.286	0.092	1.500
	ee2		360	0.473	0.227	0.085	1.040
	ee3		360	0.474	0.227	0.085	1.040
Pollution control technology progress	pa1	Environmental efficiency	360	0.275	0.240	0.010	1.000
	pa2		360	0.249	0.230	0.019	1.091
	pa3		360	0.266	0.225	0.024	1.051
Backup technology progress	bt1	Non fossil energy efficiency	360	0.303	0.280	0.023	1.772
	bt2		360	0.297	0.302	0.011	1.772
	bt3		360	0.294	0.299	0.011	1.772
Green Finance	GF	Entropy method	360	0.134	0.077	0.029	0.566
Level of foreign direct investment	fdi	Foreign direct investment/GDP	360	0.020	0.016	0.000	0.082
Environmental regulation	er	Investment in industrial pollution control/GDP	360	0.003	0.003	0.000	0.025
Education per capita	edu	Years of education per capita	360	9.599	1.616	6.764	15.451
GDP per capita	gdpc	GDP/population	360	3.330	1.904	0.663	13.030
Openness	open	Total imports and exports/GDP	360	0.235	0.333	0.002	1.784
R&D investment	RD	R&D investment/GDP	360	0.012	0.011	0.000	0.060
Square of GDP per capita	gdpc^2	Square of GDP per capita	360	14.704	18.800	0.440	169.777

## 5. Empirical Results and Analysis

### 5.1. Spatial Autocorrelation

Before we can determine whether we can adopt the spatial econometrics model, we need to test the autocorrelation first. At present, there are three common methods to test autocorrelation: Global Moran's I index, Geary C index and global G index. In this paper, the global Moran's I index is selected, and its specific calculation formula is as follows:

$$\text{Moran's I} = \frac{\sum_{i=1}^n \sum_{j=1}^n (Y_i - \bar{Y})(Y_j - \bar{Y})}{S^2 \sum_{i=1}^n \sum_{j=1}^n W_{ij}}$$

Among them,  $S^2 = \frac{1}{n} \sum_{i=1}^n (Y_i - \bar{Y})^2$ ;  $\bar{Y} = \frac{1}{n} \sum_{i=1}^n Y_i$ ,  $Y_i$  represents the level of green technology innovation in the  $i$ th

Province, including energy biased technological progress, pollution control technological progress and backup technological progress,  $W_{ij}$  is a spatial weight matrix. Moran's I is the Moran index, ranging from - 1 to 1. When the value of Moran's I is less than 0, it means that there is a negative spatial correlation. When the value is significantly greater than 0, it means that there is a positive spatial correlation. When the value is equal to 0, there is no spatial correlation. Through table 3, we can see that the Moran index values of energy biased technological progress, pollution control technological progress and backup technological progress are overwhelmingly significant, indicating that there is indeed spatial autocorrelation, so spatial econometrics model can be used for analysis.

**Table 3a.** Moran's I statistics of green technology innovation level

Year	bt1		ee1		pa1	
	Moran'I	Z value	Moran'I	Z value	Moran'I	Z value
2008	0.044**	2.204	0.072***	2.975	0.058***	2.562
2009	0.012	1.311	0.122***	4.365	0.117***	4.249
2010	0.009	1.278	0.114***	4.130	0.105***	3.901
2011	0.019	1.635	0.077***	3.116	0.115***	4.250
2012	0.038**	2.160	0.101***	3.764	0.100***	3.839
2013	-0.007	0.965	0.098***	3.654	0.073***	3.108
2014	0.104***	4.114	0.082***	3.176	-0.007	0.783
2015	0.099***	4.064	0.077***	3.045	-0.004	0.851
2016	0.062***	2.745	0.073***	2.968	0.002	1.039
2017	0.124***	4.582	0.088***	3.357	0.038**	2.081
2018	0.17***	6.051	0.091***	3.437	0.039**	2.062
2019	0.048**	2.381	0.071***	2.882	0.083***	3.306

**Table 3b.** Moran's I statistics of green technology innovation level (Continued)

Year	bt2		ee2		pa2	
	Moran'I	Z value	Moran'I	Z value	Moran'I	Z value
2008	0.067***	2.817	0.087***	3.410	0.015	1.403
2009	0.058**	2.580	0.127***	4.597	0.031*	1.877
2010	0.077***	3.146	0.111***	4.187	0.024*	1.686
2011	0.074***	3.141	0.101***	3.907	0.038**	2.194
2012	0.071***	3.009	0.113***	4.154	0.036**	2.166
2013	0.012	1.458	0.105***	3.953	0.034**	2.217
2014	0.086***	3.391	0.103***	3.876	0.035**	2.384
2015	0.095***	3.627	0.107***	3.942	0.048***	2.681
2016	0.041**	2.139	0.107***	3.911	0.034**	2.046
2017	0.104***	4.085	0.107***	3.896	0.075***	3.28
2018	0.092***	3.681	0.093***	3.509	0.074***	3.07
2019	0.07***	3.343	0.091***	3.467	0.09***	3.591

**Table 3c.** Moran's I statistics of green technology innovation level (Continued)

Year	bt3		ee3		pa3	
	Moran'I	Z value	Moran'I	Z value	Moran'I	Z value
2008	0.069***	2.857	0.088***	3.427	0.021	1.596
2009	0.057**	2.555	0.126***	4.583	0.038**	2.057
2010	0.068***	2.891	0.115***	4.274	0.040**	2.098
2011	0.067***	2.983	0.100***	3.849	0.047**	2.383
2012	0.071***	3.009	0.113***	4.154	0.046**	2.436
2013	0.012	1.458	0.105***	3.953	0.045**	2.538
2014	0.087***	3.436	0.118***	4.271	0.06***	3.034
2015	0.095***	3.627	0.107***	3.942	0.058***	2.901
2016	0.041**	2.139	0.107***	3.911	0.045**	2.327
2017	0.104***	4.085	0.107***	3.896	0.056***	2.726
2018	0.092***	3.681	0.093***	3.509	0.092***	3.545
2019	0.07***	3.343	0.091***	3.467	0.09***	3.54

Note: \*, \*\* and \* indicate significant at 10%, 5% and 1%, respectively.

## 5.2. Spatial metrology model selection

Before regression, we selected the appropriate spatial econometrics model through a series of tests. Firstly, we conduct LM test and robust LM test to verify the matching of SEM model, SAR model and SDM model; Then, we use LR

test and Wald test to test whether SDM model will degenerate into SAR or SEM model; Finally, we performed the Hausman test to determine whether to choose a fixed effect model or a random effect model. The specific test results are shown in Table 4:

**Table 4.** Spatial metrology model test

Inspection method	bt1	ee1	pa1	bt2	ee2	pa2	bt3	ee3	pa3
LM Err	2.302*	37.751***	1.856	1.230	52.707***	7.625***	1.264	51.597***	7.140***
LM Lag	1.080	2.854***	6.983***	17.433***	4.622**	0.531	8.093***	4.903**	0.193
R-LM Err	8.283***	35.963***	1.684	8.412***	48.428***	7.863***	16.816***	46.933***	8.020***
R-LM Lag	7.262***	1.065	6.811***	24.615***	0.343	0.769	23.645***	0.239	1.703
LR (SDM&SAR)	17.27**	29.84***	15.32**	21.82***	13.12*	14.12*	21.98***	14.25*	13.11*
LR (SDM&SEM)	18.36**	30.25***	10.79*	20.94***	17.90**	15.31**	20.93***	18.86**	15.98**
Wald (SAR)	17.66**	31.10***	15.89**	22.58***	13.27*	14.48*	22.73***	14.47*	13.32*
Wald (SEM)	18.91**	30.98***	10.91*	21.51***	18.12**	16.19**	21.53***	19.12**	16.76**
Hausman test	27.86***	14.33*	69.36***	28.67***	43.82***	10.57*	13.24**	55.70***	63.45***

Note: \*, \*\* and \* indicate significant at 10%, 5% and 1%, respectively.

According to the test results in Table 4, under comprehensive consideration, we choose the spatial Dubin model for empirical analysis. The results of Hausman test in the above table significantly reject the original hypothesis, and then we compare the results of individual, time and two-way fixed effect through LR test, and finally choose the spatial Dubin model of two-way fixed effect.

## 5.3. Regression results of spatial Dubin model

In Table 5, bt, ee and pa represent backup technological progress, energy biased technological progress and pollution control technological progress respectively, and the subscripts 1, 2 and 3 of these variables represent different indicators when calculating efficiency with DEA. 1 is the data of only CO2 when calculating unexpected output, 2 is the data of comprehensive three wastes when calculating unexpected

output, and 3 is the data of comprehensive three wastes when calculating unexpected output, Add CO2 and comprehensive three waste data. From table 5, we can see that in models (1) - (9), the vast majority of explanatory variables have passed the significance test, and on the whole, green finance has a positive effect on the level of green technology innovation in the province, which verifies hypothesis 1. From the regression results, we can also see that the impact on backup technological progress, energy biased technological progress and pollution control technological progress will be different, but most models also pass the significance test for their spatial autocorrelation coefficients, indicating that there is a significant spatial dependence on the level of green technology innovation under the influence of spatial interaction. The interaction term between green finance and spatial weight matrix is significant and the coefficient is negative, indicating that the improvement of green finance level in this region will restrain the development of green

technology innovation in neighboring areas to a certain extent. This may be due to the "siphon effect" in areas with a higher level of green financial development, attracting surrounding talents, capital flow and other resources to tilt towards themselves, thus crowding out the development resources of surrounding areas, resulting in restrictions on the innovation and development of green technology in surrounding areas.

This paper explores the spatial spillover effect of green finance on the level of green technology innovation. Considering that green finance will not only affect the level of green technology innovation in this region, but also affect other regions, in order to better study this "feedback effect", referring to relevant research, this paper further estimates the three decomposition effects of green finance on the level of green technology innovation, namely, direct effect, indirect effect and total effect, The specific regression results are shown in Table 6:

**Table 5.** Spatial regression results of green finance on green technology innovation level

variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	bt1	ee1	pa1	bt2	ee2	pa2	bt3	ee3	pa3
GF	2.751*** (0.488)	2.020*** (0.328)	-1.194*** (0.372)	0.515 (0.419)	1.280*** (0.199)	0.960*** (0.273)	0.505 (0.417)	1.276*** (0.200)	1.075*** (0.255)
fdi	0.024 (0.992)	0.398 (0.662)	0.410 (0.755)	1.327 (0.849)	0.331 (0.404)	0.522 (0.554)	1.119 (0.845)	0.381 (0.405)	0.155 (0.517)
er	-4.453 (4.456)	-9.011*** (2.980)	3.307 (3.397)	-2.609 (3.823)	-5.801*** (1.817)	-4.248* (2.494)	-1.211 (3.804)	-6.389*** (1.824)	-3.181 (2.328)
edu	-0.061 (0.046)	-0.025 (0.031)	-0.016 (0.035)	-0.031 (0.040)	-0.055*** (0.019)	-0.044 (0.026)	-0.043 (0.040)	-0.050*** (0.019)	0.009 (0.024)
gdpc	-0.151** (0.066)	0.181*** (0.044)	0.017 (0.050)	-0.060 (0.056)	0.084*** (0.027)	-0.091** (0.037)	-0.059 (0.056)	0.084*** (0.027)	-0.090*** (0.034)
open	0.401*** (0.092)	0.149** (0.062)	0.248*** (0.070)	0.376*** (0.079)	0.249*** (0.038)	0.200*** (0.051)	0.385*** (0.079)	0.245*** (0.038)	0.222*** (0.048)
gdpc2	0.012*** (0.004)	-0.006** (0.003)	0.005* (0.003)	0.008*** (0.003)	0.000 (0.002)	0.009*** (0.002)	0.008** (0.003)	0.000 (0.002)	0.009*** (0.002)
RD	-2.451 (2.725)	1.101 (1.823)	-4.715** (2.079)	-4.087* (2.336)	-2.032* (1.113)	-3.971*** (1.525)	-4.518* (2.325)	-1.863* (1.117)	-2.822** (1.423)
W×GF	-2.522 (2.935)	-7.758*** (1.951)	2.239 (2.219)	-4.365* (2.480)	-2.349** (1.194)	0.224* (1.617)	-4.350* (2.469)	-2.317* (1.198)	-0.847 (1.516)
W×fdi	21.029*** (6.606)	4.331 (4.427)	-6.207 (5.036)	9.008 (5.668)	2.206 (2.697)	7.002* (3.697)	9.896* (5.641)	1.822 (2.707)	3.588 (3.454)
W×er	-11.252 (31.920)	-4.939 (21.450)	0.671 (24.291)	-6.696 (27.414)	-6.141 (13.179)	1.712 (17.863)	5.024 (27.222)	-11.545 (13.303)	-3.590 (16.698)
W×edu	-0.515 (0.318)	-0.292 (0.213)	0.044 (0.242)	-0.334 (0.273)	-0.154 (0.130)	-0.038 (0.178)	-0.311 (0.271)	-0.167 (0.130)	-0.052 (0.166)
W×gdpc	-1.138** (0.443)	0.003 (0.302)	0.281 (0.337)	-0.492 (0.380)	0.029 (0.183)	-0.729*** (0.248)	-0.535 (0.378)	0.047 (0.183)	-0.731*** (0.231)
W×open	0.344 (0.553)	-1.145*** (0.369)	1.276*** (0.423)	0.575 (0.479)	-0.130 (0.229)	-0.017 (0.311)	0.650 (0.478)	-0.149 (0.230)	-0.164 (0.291)
Wgdpc2×	0.068*** (0.025)	-0.005 (0.017)	-0.010 (0.019)	0.030 (0.021)	-0.004 (0.010)	0.038*** (0.014)	0.033 (0.021)	-0.005 (0.010)	0.039*** (0.013)
W×RD	-1.015 (12.951)	7.739 (8.708)	-8.856 (10.007)	2.304 (11.103)	-2.461 (5.279)	0.349 (7.273)	2.316 (11.054)	-2.458 (5.298)	10.016 (6.776)
ρ	-0.366 (0.224)	-0.095 (0.196)	-1.235*** (0.235)	-0.410* (0.237)	-0.499** (0.214)	-0.860*** (0.239)	-0.452* (0.240)	-0.518** (0.215)	-0.844*** (0.231)
σ <sup>2</sup>	0.020*** (0.001)	0.009*** (0.001)	0.011*** (0.001)	0.015*** (0.001)	0.003*** (0.000)	0.006*** (0.000)	0.014*** (0.001)	0.003*** (0.000)	0.005*** (0.000)
N	360	360	360	360	360	360	360	360	360

Note: the corresponding P values are in brackets, and \*, \*\* and \*\*\* indicate significant at 10%, 5% and 1% levels, respectively.

**Table 6.** Direct, indirect and total effects of green finance on the level of green technology innovation

variable	(1)			(2)			(3)		
	Direct effect	Indirect effect	Total effect	Direct effect	Indirect effect	Total effect	Direct effect	Indirect effect	Total effect
GF	2.817*** (0.505)	-2.533 (2.284)	0.284* (2.308)	2.053*** (0.339)	-7.493*** (2.339)	-5.440*** (2.403)	-1.347*** (0.412)	1.925* (1.124)	0.578 (1.408)
variable	(4)			(5)			(6)		
	Direct effect	Indirect effect	Total effect	Direct effect	Indirect effect	Total effect	Direct effect	Indirect effect	Total effect
GF	0.601 (0.435)	-3.339* (2.000)	-2.739 (2.016)	1.345*** (0.207)	-2.304** (0.864)	-0.689* (0.864)	0.985*** (0.292)	-0.265 (0.944)	0.720* (0.914)
variable	(7)			(8)			(9)		
	Direct effect	Indirect effect	Total effect	Direct effect	Indirect effect	Total effect	Direct effect	Indirect effect	Total effect
GF	0.597 (0.433)	-3.251* (1.934)	-2.654 (1.945)	1.342*** (0.207)	-2.003** (0.855)	-0.661* (0.854)	1.137*** (0.272)	-0.952 (0.886)	0.184* (0.861)

Note: the corresponding P values are in brackets, and \*, \*\* and \* indicate significant at 10%, 5% and 1% levels, respectively.

From the regression results in Table 6, we can see that the direct effect of green finance on reserve technological progress and energy biased technological progress is positive, while the spatial spillover effect produced by green finance is negative, indicating that green finance directly promotes reserve technological progress and energy biased technological progress, but the spatial effect caused by green finance will restrain neighboring areas, as we have said before, this may be due to the existence of resource competition, and areas with high levels of green financial development will attract more resources for their own development. For the progress of pollution control technology, through models (3), (6) and (9), we can see that in the calculation of unexpected output, the selected standards are different, and their results are also different, but generally speaking, green finance also has a significant direct role in promoting the progress of pollution control technology, but it also has a negative spatial spillover effect on neighboring areas.

## 6. Conclusions and Policy Recommendations

Green finance is an extension of the traditional financial industry, which aims to promote China's environmental protection and sustainable economic and social development. Based on the panel data of 30 provinces (cities and autonomous regions) in China from 2008 to 2019, this paper uses spatial Dubin model to analyze the impact of green finance on the level of green technology innovation in China. The specific conclusions are as follows: first, green finance has a significant role in promoting the improvement of the level of green technology innovation in the region; Secondly, the spatial spillover effect caused by green finance will restrain the development of green technology innovation in neighboring areas to a certain extent.

Based on the above conclusions, we put forward the following policy suggestions: first, improve the policy system and promote the development of green finance. Since China implemented the green financial policy, after years of practical exploration, the "five pillars" of green finance, namely, green financial standard system, environmental information disclosure, incentive and restraint mechanism, product and market system and international cooperation, have begun to take shape, and are gradually playing the "three major functions" of resource allocation, risk prevention and price discovery. However, compared with traditional finance,

green finance still accounts for a small proportion in the market, which is difficult to meet the capital flow and various resource elements of industrial technological innovation and structural upgrading. Therefore, we should formulate a set of unified standards, divide industrial projects more carefully, clarify the object and scope of green financial products and services, promote the unification of China's green financial system, and on this basis, expand the scale of green finance, increase the proportion of green finance, and innovate green financial tools, so as to better serve enterprises for green technological innovation and green transformation. At the same time, it can also build a trading platform related to green finance and green technology innovation, so that users can obtain more information at a lower cost, and realize the transfer of green technology achievements and the financing of property rights more quickly; Second, build a cross regional linkage mechanism for green technology innovation. Innovation is not the independent development of regions and enterprises, but the result of mutual coordination, cooperation and interaction between different subjects. Therefore, we should build a linkage mechanism for green technology innovation among regions, and encourage economically developed regions to radiate and drive underdeveloped regions to carry out technological innovation and R&D. At the same time, it can also guide technical exchanges and resource sharing among provinces and cities, so as to form a situation of industrial complementarity and mutual promotion. While building a linkage mechanism, we should also pay attention to the different situations of different provinces and cities, whether in terms of government support, market environment or economic development level, there will be some differences, so we can establish a long-term working mechanism and system to ensure that different provinces and cities can implement policies suitable for their own development level and model. Third, promote the coordinated development between green finance and green technology innovation system. To establish a perfect green technology innovation system and ensure the cash flow needed in the process of technological innovation, it is inevitable that it is inseparable from the support of green finance. Therefore, we must open up the channels for green finance to support green technology innovation, transport idle funds in society to green industries and green projects more efficiently and conveniently, and meet the capital needs in the process of green technology innovation. At the same time, we should better integrate green finance and green technological

innovation, pay attention to the coordinated development of green financial system and green technological innovation system, and form a good development trend of mutual promotion and support between green finance and green technological innovation.

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