Spatial Effects of Green Technology Innovation on Provincial Environmental Pollution in China

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Spatial Effects of Green Technology Innovation on Provincial Environmental Pollution in China

Abstract: In order to promote regional environmental pollution control, this paper takes China's provinces as a research perspective, 2008-2019 as the time dimension, based on the entropy method to measure China's provincial environmental pollution comprehensive indicators, and introduces models such as panels, thresholds and mediation effects to focus on the relationship between technological innovation and environmental pollution, the research has found that: (1) Green technological innovation has direct suppression effects on China's provincial environmental pollution; (2) Green technological innovation has the threshold effect of marketization and R&D investment in the process of restraining environmental pollution; (3) Industrial structure upgrading and energy consumption structure play an mediation effect in the process of green production technology innovation to suppress environmental pollution, but the mediation effect still has a long way to go; (4) After considering endogenous issues, the path of green technological innovation to restrain environmental pollution is still significant. The research conclusions can provide a reference for constructing a scientific and reasonable environmental pollution control path in accordance with local conditions in China's provinces.

Keywords: green technological innovation; environmental pollution; threshold effect; mediation effect

1 Introduction

In the post-epidemic era, global climate response and economic recovery are facing unprecedented challenges. The brown economy dominated by industrial civilization has triggered global climate changes, leading to frequent occurrences of extreme climates such as drought, floods, and melting glaciers (Song et al., 2020). The international community has gradually realized that environmental pollution has become a global non-traditional threat and a major challenge facing mankind. Strengthening the global climate governance cooperation mechanism is on the road (Huang et al., 2017; Song et al., 2018). Under the guidance of the reform and opening policy, China's economy has developed rapidly, but the factor-driven and investment-driven extensive economy has brought serious environmental pollution to China (Chase-Dunn et al. 2007), Resulting in frequent domestic environmental pollution incidents, have seriously threatened human life, health and economic development (Barcena-Ruiz et al. 2013). According to the latest research, continuous environmental pollution will expose people to multiple risks, including stagnant economic growth, impaired health, food and water shortages, frequent extreme weather events, and rising sea levels, especially in underdeveloped and more vulnerable areas. It can be imagined that China is facing tremendous pressure on environmental pollution control (Singhania M et al. 2013). Although the government has increased the control of environmental pollution through a series of policies and regulations, China's environmental pollution control still has a long way to go (Liu XR et al. 2020), and it has become a key source of obstacles facing China's economic transformation and upgrading and the pursuit of high-quality economic development. Arouse the vigilance of the political and academic circles, and launch the exploration of the coordinated development of economy and environment.

During the "13th Five-Year Plan", China clearly put forward the five development concepts of "innovation, coordination, greenness, openness, and sharing". During the "14th Five-Year Plan"

period, it was integrated with General Secretary Xi's "Two Mountains Theory" to deepen it (Ou JF et al.2020; Liang Z et al.2020) . So far, China's economic development model has officially changed from factor-driven to innovation-driven. In this process, green development promotes high-quality economic development and gradually becomes the main theme of social development"(Wang H et al.2019). The Chinese government also clearly pointed out that green Technological innovation plays a key leading role in climate governance, and the regional environmental governance model has also changed from terminal governance to a comprehensive governance model based on source prevention and governance(Wu G et al.2019). The innovation drive is one of the key elements of environmental source governance and comprehensive governance (Wu G et al.2019;Liu Y et al.2018), has gradually attracted the attention of academia and politics. Green technological innovation can reduce energy consumption and pollutant emissions per unit of output value, coordinate with regional economic growth, waste emissions, and industrial structure upgrades to match the development(Hu, W et al.2018).However, at the current stage, the academic circles mostly take scientific and technological innovation as the research perspective, and the green technology innovation research perspective is less. Facing the special new economic development trend in China, the academic circles need to solve the path of green technology innovation and environmental pollution, and support local governments to formulate science Reasonable innovation policies, consolidate the path to restrain environmental pollution in the province, and promote the high-quality development of the provincial economy That is (1) Does green technological innovation effectively support environmental pollution control? (2) Does green technological innovation have spillover effects, mediation effects, and thresholds in suppressing provincial environmental pollution? (3) Under the premise of considering endogenous issues, does green technology innovation still have the effect of inhibiting environmental pollution. In-depth research and thinking on the above issues will help improve China's environmental governance efficiency and rebuild China's environmental image. Achieving the responsibility of a major power is of the utmost importance.

In order to fill the academic gap and answer the aforementioned questions, This paper takes China's provinces as the research perspective and takes 2008-2019 as the time dimension. Based on the entropy method, this paper calculates the comprehensive environmental pollution index of China's provinces. Panel, threshold and intermediary effect models are introduced to focus on the relationship between green technology innovation and environmental pollution, and the marginal conditions of threshold variables are clarified. Analyze the mediation effect of green innovation in the process of restraining environmental pollution. The rest of this study is outlined as follows: theory and hypotheses are elaborated in section 2, while methods are indicted in Section 3. Section 4 and 5、6 presents the empirical analysis and expansion analysis, respectively. Section 6 draws the conclusions.

2. Theory and Hypotheses

2.1 Direct effect

As an important means of environmental pollution control, green technological innovation has gradually become an important part of government policies (Dong Z et al.2019) ; The Chinese government has repeatedly emphasized the promotion of ecological civilization construction, realizing the harmonious symbiosis of economy-society-environment, and advancing the market-oriented green

technology innovation system, and use it as an important tool for the construction of ecological civilization;Grossman and Krueger(1995) explained the formation mechanism of EKC During the process, the “technical effect” was proposed for the first time, and believed that in the process of economic growth, technological advancement can effectively improve the comprehensive utilization efficiency of resources, reduce the input of factors, and weaken the impact of enterprise production on the environment, and it is represented by green technology. The innovative development-operation and renewal of green technology can effectively reduce the discharge of wastewater, waste gas and solid waste from enterprises, and achieve the effect of restraining regional environmental pollution. In addition, green technological innovation can accelerate the upgrading of the industrial structure, eliminate outdated production capacity, achieve the goal of improving quality and efficiency, and indirectly reduce the regional environmental pollution index(Costantini V.et al.2019). Therefore, this research believes that green technological innovation can effectively reduce the comprehensive index of regional environmental pollution, and proposes the first research hypothesis:

H1: Green technology innovation can effectively reduce the regional environmental pollution composite index.

2.2 Threshold effect

2.2.1 The threshold effect of R&D investment

Green technological innovation is inseparable from research and development investment, and the amount of research and development investment is directly related to the output of green technological innovation. Li G(2018)believes that with the increase in R&D investment of enterprises, the clean production and green technology innovation technologies of enterprises will be more in line with the expectations of the public, and the environmental pollution control technology system will be further improved, and the effectiveness of environmental pollution control will be improved; At the same time, the increase in R&D investment will reduce corporate R&D risks, correct market failures caused by the positive externalities of green technology innovation, reduce regional differences in green technology innovation, and improve the effectiveness of restraining environmental pollution(Rennings K et al.2000); in addition, R&D investment can ensure research institutes The necessary funds are needed to support the normal operation of innovation entities, improve the output efficiency of green technology innovation, and achieve the purpose of achieving economic benefits while reducing the regional environmental pollution index(Ghisetti C et al.2015). Based on this, this research proposes a second research hypothesis:

H2: Green technological innovation has a threshold effect of R&D investment in the process of restraining regional environmental pollution.

2.2.2 The threshold effect of marketization degree

With the improvement of marketization degree, inter-regional green innovation cooperation will be deepened, promote the upgrading and transformation of green technology, and promote the overall green development of the region through the spillover effect of green innovation , Contribute to the construction of ecological civilization; at the same time, the optimal allocation of regional green innovation elements largely depends on the degree of marketization (Yin, X et al.2015) . Only when the degree of regional marketization is high, the availability and optimal allocation rate of regional innovation elements will be more reasonable,This means that the degree of regional marketization is positively correlated with the flow of regional innovation factors and innovation efficiency (Guang H

et al.2011) ; in addition, with the development of marketization, corporate financing channels have become broader, especially with the development of green credit, and regional innovation entities have become more important. Inclination towards collaborative innovation and gradually increasing activity has improved the regional green innovation system and strengthened the restraint effect of green innovation on regional environmental pollution. Based on this, this research proposes the third hypothesis:

H3:Green technological innovation has a threshold effect of marketization degree in the process of restraining regional environmental pollution.

2.3Mediation effect

2.3.1The mediation effect of industrial structure upgrading

Behind the rapid development of China's economy, the upgrading and evolution of the industrial structure are indispensable(Yu H et al.2011), especially under the new normal of economic development. From high growth to high-quality development,Continuous upgrading and optimization of the industrial structure is a prerequisite for high-quality economic development (Lei, C et al.2011) . It can achieve the goal of environmental pollution control under the goal of ensuring high-quality economic development, and truly achieve a win-win situation between the economy and the environment.The upgrading of industrial structure is an important driving factor for regional environmental pollution control, and green technological innovation is the key factor which promoting the upgrading of industrial structure and improving regional environmental pollution. The impact of the upgrading of its industrial structure and indirect suppression of environmental pollution are mainly reflected in the following Several levels (Geng, D et al.2018) . ①Green technological innovation promotes clean production through the use of new processes and increases the productivity of the original industry to achieve the purpose of energy saving and emission reduction; ②Green technological innovation promotes the separation of new industries from the original industries, or creates new industries, and creates new business areas , Adopt new production methods, inject new vitality and vitality into the industry, promote the upgrading of the industrial structure, and achieve the purpose of reducing environmental pollution; ③Green technological innovation has spawned new market demand: demand is an important driving force for the upgrading of industrial structure, green technology Innovation promotes the entry of new products into the market, gradually changes the market demand structure, promotes the upgrading of the industrial structure, and achieves the goal of energy saving and emission reduction; ④Green technological innovation improves the industrial employment structure: Green technological innovation brings more clean processes to the industry and spawns emerging industries , Improve the traditional employment structure, indirectly improve the regional industrial structure, and help regional environmental pollution control (Tao, W.et al.2013) .

H4: The upgrading of industrial structure plays an intermediary effect in the process of green technological innovation in suppressing environmental pollution.

2.3.2 The mediation effect of energy consumption structure

In the context of the construction of national ecological civilization, the environmental effects of green technological innovation are gradually on the right track and become the scientific and technological direction of the country's future development, which can lead to green economic growth by optimizing the energy consumption structure(Lei, C et al.2011). ①Green technological innovation reduces the consumption intensity of fossil fuels such as coal by improving production processes, increasing

investment in green processes, and changing traditional production models, thereby indirectly reducing regional environmental pollution(Lei, C et al.2021); ②Green technological innovation enhances energy consumption by improving enterprise production efficiency Efficiency, reduce coal and other fossil energy consumption, reduce waste gas emissions, and achieve the purpose of restraining regional environmental pollution(Lei, C et al.2021; Ying, N et al.2011); ③Green technological innovation promotes high pollution and high energy consumption industries to redefine their production processes, promote the transformation of industrial consumption structure, and reduce fossil energy as a whole Consumption; ④The improvement of green technology innovation will improve the development level of new energy industry, promote the development of new energy industry, change the traditional energy consumption structure, and finally achieve the purpose of restraining regional environmental pollution; ⑤In addition, green technology innovation will improve the efficiency of energy use , Change the market supply and demand structure of coal and other fossil fuels, promote clean and safe energy alternatives, and optimize the energy consumption structure(Ying, N et al.2011). It can be seen that green technological innovation achieves the goal of optimizing the energy consumption structure through a variety of ways, which is currently one of the important ways to solve regional environmental pollution.

H5: In the process of green technology innovation in suppressing environmental pollution, the energy consumption structure plays an intermediary effect.

2.4 Theoretical mechanism model

With reference to existing literature, this study built a theoretical mechanism model, portraying the Impact path of green technology innovation to environmental pollution based on above mentioned hypotheses, which is shown in figure 1.

Figure 1 Impact path of green technology innovation to environmental pollution

3. Methods

3.1 Model and methodology

Selection and construction of spatial measurement model: Since the SDM (Spatial Dubin model) model combines the advantages of SAR (Spatial lag model) and SEM (Spatial error model) models; it can not only analyze the spatial correlation between green technological innovation and environmental

pollution, but also explore the spatial impact of random shocks. Therefore, with application of SDM model, this study constructed the modified model to capture the affecting mechanism of green technological innovation on environmental pollution, which is shown as follows:

$$EP_{it} = \beta_0 + \rho WEP_{it} + \beta_1 GT_{it} + \beta_2 X_{it} + \theta_1 WGT_{it} + \theta_2 WX_{it} + \varepsilon_{it} \quad \text{Formula 1)}$$

In particular, EP_{it} , GT_{it} refer to the green technological innovation and environmental pollution in the t-th year in i region respectively; X_{it} is control variable; W indicates the spatial weight matrix; and ε_{it} represents the random disturbance item. When $\theta_i = 0$, the SDM model will degenerate into a SAR model while the SDM model will degenerate into an SEM model if $\theta_i = -\beta_i$.

Exploratory spatial analysis: Before application of spatial measurement model, this study employed Moran's index to analyze the spatial dependence of green technological innovation and environmental pollution variables among different provinces. In detail, the Global Moran's I falls between -1 and 1. In particular, 0 to -1 indicates negative correlation, while 0 to 1 implies positive correlation.

$$I = \frac{n \sum_{i=1}^n \sum_{j=1}^n w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^n \sum_{j=1}^n w_{ij} \sum_{i=1}^n (x_i - \bar{x})^2} = \frac{\sum_{i=1}^n \sum_{j=1}^n w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{S^2 \sum_{i=1}^n \sum_{j \neq i} w_{ij}} \quad \text{Formula 2)}$$

Spatial matrix: Based on the panel data model, a spatial weight matrix was incorporated to clarify the positional relationship among individuals. The mainstream weights include geographic weight matrix, economic weight matrix and neighbor weight matrix. Due to the competition among regional governments, Environmental pollution source not only comes from the local area, the environmental pollution in the neighboring area also causes harm to the local environment. Therefore, the relationship among the variables should be discussed taking geographical weight distance into account.

$$\text{Geographic distance: } W_{ij} = 1/d_{ij}, \quad i \neq j \quad \text{Formula 3)}$$

Threshold model: In order to detect the impact path of green technological innovation in the process of environmental pollution control, this study uses marketization degree and R&D investment as threshold variables, and under the coordination of threshold models, discuss the possible threshold effects of marketization and R&D investment in the process of green technological innovation restraining regional environmental pollution, and its threshold model is as follows.

$$EP = a_0 + a_1 GT\{RDI \leq \varphi\} + a_2 GT\{RDI \geq \varphi\} + \tau X_{it} + \varepsilon_{it} \quad \text{Formula 4)}$$

$$EP = a_0 + a_1 GT\{MD \leq \varphi\} + a_2 GT\{MD \geq \varphi\} + \tau X_{it} + \varepsilon_{it} \quad \text{Formula 5)}$$

3.2 Data and Index selection

Considering the availability of data and representativeness of the research, panel data of 30 selected provinces and cities in China from 2008 to 2019 were collected from published data sources such as 《China Statistical Yearbook》, 《China Environment Statistical Yearbook》 and 《China Industrial Statistical Yearbook》.

3.2.1 Explained variable:

Environmental pollution (EP): Environmental pollution mainly includes water pollution, air pollution, solid waste pollution, noise pollution, etc. The academic circles have not yet fully determined the comprehensive indicators that reflect the overall level of environmental pollution in a certain area. Most studies still use a single indicator. Because a single indicator cannot determine the environmental pollution situation well, in order to scientifically reflect the regional environmental pollution situation, this study uses the research of Gui H and other scholars for reference (Gui H et al.2021), Taking industrial sulfur dioxide, carbon dioxide, industrial wastewater, and general industrial solid waste as indicators, borrowing the entropy method and the comprehensive index of environmental pollution to characterize environmental pollution.

3.2.2 Core explanatory variable

Green Technology Innovation (GT): Green technology innovation plays a pivotal role in reducing pollutants and reducing environmental pressure. There are still differences in the definition of indicators in the academic circle. The article borrows the practice of Dong Zhiqing (Dong Z et al.2019) and other scholars to characterize green technological innovation with the number of green patents. The specific method is to use the green patent classification code listed by WIPO according to the type of green patents, Patent address, classification code, total number of green patents granted by WIPO in China.

3.2.3. Threshold variables

R&D investment (RDI): R&D investment is the life source of green technology innovation, which directly determines the depth and breadth of green technology innovation research, and then affects the suppression effect on waste pollution. Based on this, this study uses the logarithm of R&D investment as the threshold variable, To Explore the possible threshold effect of R&D investment.

Degree of marketization (MD): When the degree of marketization is high, the availability and optimal allocation rate of regional innovation elements will be more reasonable, perfect the regional green innovation system, and strengthen the inhibitory effect of green innovation on regional environmental pollution. Based on this, this study uses the Fan Gang marketization index to characterize the degree of marketization in China's provinces. The larger the marketization index, the higher the degree of marketization.

3.2.4 Mediating variable

Industrial structure upgrading (ISU): Industrial structure upgrading refers to the evolution of industries from low-end industries to high-end industries. In order to scientifically characterize the degree of industrial structure upgrading, this study constructed an industrial structure-upgrading index according to Wang et.al 's (2015) industrial structure upgrading method. The specific formula is as follows:

$$ISU = W_1 + 2W_2 + 3W_3 \quad \text{Formula 7)}$$

In particular, W_1, W_2, W_3 represent the proportions of the three major industries, while 1, 2, and 3 are the weights of three industries. The higher the comprehensive index indicates the more significant the upgrading of the industrial structure.

Energy consumption structure (NY): Energy consumption is the main “supplier” of provincial carbon emission reduction. The optimization of energy consumption structure can effectively reduce exhaust gas emissions. Based on this, Draw on the research achievements of Li Kai and Qi Shaozhou. (Li K et al.2011) The ratio of total energy consumption to total energy consumption characterizes the energy consumption structure.

3.2.5 Control variables

Foreign direct investment (FDI): Foreign direct investment has been argued to have two-side effects, which are inextricably linked to the environmental pollution of China’s green economy. In this study, FDI was measured by the logarithm of the actual total amount of foreign investment.

Industrial structure upgrading (ISU): Industrial structure upgrading refers to the evolution of industries from low-end industries to high-end industries. In order to scientifically characterize the degree of industrial structure upgrading, this study constructed an industrial structure-upgrading index according to Wang et.al 's (2015) industrial structure upgrading method. The specific formula is as follows:

$$ISU = W_1 + 2W_2 + 3W_3 \quad \text{Formula 8)}$$

In particular, W_1, W_2, W_3 represent the proportions of the three major industries, while 1, 2, and 3 are the weights of three industries. The higher the comprehensive index indicates the more significant the upgrading of the industrial structure.

Industrial level (ID): Industrialization and regional environmental pollution are complicatedly related. The traditional industrial system is considered as the main polluting source of regional environment. However, with the development of industrial intelligence, whether the modern industrialization level alleviates regional environmental pollution thus promoting green development remains the question. Hence, industrial level was measured by the ratio of secondary industry to regional GDP in current study.

Urbanization level (URB): During the process of urbanization expansion, a large number of energy-intensive products such as steel and cement are consumed for infrastructure construction and housing construction, resulting in a large amount of pollutant emissions. Therefore, Therefore, urbanization is another cause of environmental degradation. This study employed the proportion of urban population to total population at the end of the year to characterize the level of urbanization.

Energy consumption (EN): In the process of national economic development, the energy consumption

is mostly coal and other fossil fuels, which consume a large amount and are the main "suppliers" of exhaust emissions. Based on this, this study uses the total energy consumption To characterize energy consumption .

Table 1 Descriptive Statistics

Variable	Obs	Mean	SD	Min	Max
Explained variable	EP 360	0.291	0.216	0.000	0.874
Core explanatory variables	GT 360	6.759	1.496	2.079	10.097
Threshold variables	RDI 360	15.641	1.402	11.436	18.357
	MD 360	6.445	1.927	2.330	11.403
Mediating variable	ISU 360	2.348	0.131	2.102	2.832
	NY 360	0.414	0.152	0.012	0.724
	EN 360	9.377	0.672	7.034	10.625
	ID 360	45.232	8.681	16.200	61.512
Control variables	URB 360	55.521	13.186	29.11	89.632
	FDI 360	14.413	2.003	6.552	17.074
	GDP 360	9.526	0.922	6.681	11.485

4. Empirical analysis

4.1 Spatial correlation analysis: In order to verify the spatial correlation between green technological innovation and environmental pollution, this paper constructs a weighted distance matrix based on geographic distance, and calculates the global Moran's I index values of 30 provinces and cities in China from 2008 to 2019. The results are shown in Table 2. Moran's I for green technology innovation and environmental pollution is significantly positive at a significant level, indicating that there is a certain spatial correlation between green technology innovation and environmental pollution between provinces and cities in China. The spatial measurement borrowed for this study is Analysis tools provide a scientific basis.

Table 2 2008-2019 Moran's I Index of green technological innovation and environmental pollution

Year	EP	GT	Year	EP	GT
2008	0.394*** (2.650)	0.360*** (2.436)	2014	0.439*** (2.942)	0.224* (1.638)
2009	0.383*** (2.588)	0.237** (1.752)	2015	0.443*** (2.960)	0.231** (1.769)
2010	0.405*** (2.744)	0.253** (1.794)	2016	0.431*** (2.886)	0.269** (1.908)
2011	0.416*** (2.816)	0.255** (1.848)	2017	0.424*** (2.845)	0.250** (1.754)
2012	0.428*** (2.894)	0.254** (1.820)	2018	0.441*** (2.974)	0.241** (1.713)
2013	0.449*** (3.021)	0.237** (1.728)	2019	0.443*** (2.985)	0.274** (1.903)

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

On the other hand, this study drew the Moran's I Scatter plot based on the geographical weight matrix and selected data through STATA12 software to further analyze the spatial relevance of green technological innovation and environmental pollution. As shown in the figure 2 and 3, the green technological innovation and environmental pollution of various provinces and cities are mainly concentrated in the first and third quadrants, indicating a strong spatial aggregation effect, which verifies the spatial correlation of green technological innovation and environmental pollution in the selected areas.

Moran's I = 0.394 EP2008

Moran's I = 0.443 EP2019

Z

Z

Figure 2 Moran Scatter Chart of Environmental Pollution

Moran's I = 0.360 GT2008

Moran's I = 0.274 GT2019

Z

Z

Figure 3 Moran Scatter Chart of Green Technological Innovation

4.2 Spatial model selection: In order to scientifically demonstrate the relationship between the variables in this study, a variety of spatial measurement models are introduced in the article for empirical analysis. According to the research conclusion of Anselin (Anselin L 1988), the P value of the Hausman test of this research model is 0, and the significance test verifies that the fixed effects model is more suitable for this research than the random effects model. The LM and R-LM test results show that the SAR model is better than the SEM model, and the WALD and LR tests show that the SDM model has passed the significance test and cannot be degraded to SAR or SEM. The test results verify that the SDM model is more effective. Therefore, the follow-up analysis mainly Analyze around the SDM model.

Table 3 Model Testing

Testing method	Statistics	Probability	Testing method	Statistics	Probability
LM-Spatial_Lag	20.165	0.000	Wald-Spatial_Lag	27.950	0.000
Robust-LM-Spatial_Lag	0.209	0.313	LR-Spatial_Lag	41.923	0.000
LM-Spatial_Erro	20.393	0.000	Wald-Spatial_Erro	77.351	0.000
Robust-LM-Spatial_Erro	0.437	0.417	LR-Spatial_Erro	76.537	0.000
Hausman	36.890	0.001			

4.3 Direct effect relationship: It can be seen from Table 4 that the effect path of green technological innovation on China's provincial environmental pollution is -0.077***, passing the 1% significance level. It is verified here that green technological innovation can significantly suppress regional environmental pollution in China. For every one percentage point increase in green technological innovation, environmental pollution can be reduced by 0.077 percentage points. H1 is valid. The reason is that green technology innovation guides enterprises to green production, improve the comprehensive utilization rate of resources and energy in the production process, reduce the resource and energy consumption rate per unit output, reduce pollution emissions, and achieve a restraining effect on provincial environmental pollution.

Table 4 Estimated results of Green Technology Innovation and Environmental Pollution

Variable	SEM		SAR		SDM	
	β	T	β	T	β	T
GT	-0.099***	-6.440	-0.081***	-5.780	-0.077***	-5.230
ID	-0.001	-0.900	-0.002*	-1.830	-0.002**	-2.300
EN	0.329***	15.000	0.357***	18.400	0.353***	15.480
FDI	0.013***	3.590	0.016***	4.630	0.010***	2.740
URB	-0.001	-0.920	0.001	0.150	-0.001	-0.620
ISU	0.070	0.680	0.078	0.790	-0.049	-0.460
GDP	-0.242**	-2.660	-0.332***	-3.900	-0.505***	-5.690
GDPP	0.013***	2.870	0.016***	3.780	0.026***	5.820
w*GT					-0.033	-1.380
w*IN					-0.001	-0.440
w*EN					0.137***	2.880
w*FDI					0.008**	1.680
w*URB					0.003**	2.700
w*ISU					0.127	0.860
w*GDP					0.223*	1.580
w*GDPP					-0.014**	-2.040
ρ			0.343***	9.950	0.205***	3.430
λ	0.406***	6.520				
	R-sq	0.792	R-sq	0.8338	R-sq	0.8654
	Log-L	313.102	Log-L	337.838	Log-L	358.786
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ GDP=GDP*GDP						

Regarding the control variables, there is a significant "U"-shaped nonlinear relationship between economic growth and environmental pollution, which verifies the existence of the Environmental Kuznets Curve (EKC) in China; Foreign investment has aggravated China's provincial environment Pollution (0.010***), the possible cause is the "low competition" between governments or the hero of GDP. The unrestricted introduction of foreign capital has aggravated the environmental pollution of the province. The research conclusions verified the "pollution paradise hypothesis", Negated the "pollution halo theory"; Energy consumption (0.353***) is still one of the main sources of environmental pollution in China's provinces. It is urgent to strengthen new energy development, reduce fossil fuel consumption, and optimize energy consumption structure. However, from the perspective of the restraint relationship, industrialization has restrained environmental pollution in China's provinces and cities (-0.001***), mainly because China has gradually upgraded and optimized its industrial structure in recent years, integrating industrialization and informatization, and improving the quality of industrial output value. To a certain extent, the regional environmental pollution has been suppressed; however, although the development of urbanization and the upgrading of industrial

structure have a certain inhibitory effect on the environmental pollution of China's provinces, it is not significant. The reason is that China's provinces are promoting the process of new urbanization and industrial structure upgrading. China's effectiveness in suppressing environmental pollution is emerging, but the road to new urbanization and industrial structure upgrading still has a long way to go.

4.4 Endogenous tests

Due to two-way causality or omitted variables, there may exist certain endogenous problems, leading to deviations in research. Therefore, endogenous analysis is desirable. This study applied SYS-GMM and treated lag period of environmental pollution as an instrumental variable to explore the endogenous problem, which resolves the inconsistent and biased dilemmas of model estimation as well as weakness associated with DIF-GMM (Arellano et al.1991; Blundell et al.1998). With reference to research conducted by Jing and Zhang (2014), this study considered lag period of green technology innovation as the explanatory variable and integrated it into the regression model to deal with endogenous problem caused by omitted variables. Therefore, the dynamic characteristics of environmental pollution can be described and other factors affecting environmental pollution can be involved into the model, which eventually reduce the deviation of conclusions.

Table 5 Endogenous tests-----SYS-GMM test

EP	β	SE.	t-value	p-value	置信区间			
L.EP	0.871***	0.029	29.60	0.000	0.814	0.929		
GT	-0.015***	0.004	-3.41	0.001	-0.023	-0.006		
L.GT	0.008**	0.003	2.52	0.012	0.002	0.015		
IN	-0.001**	0.001	-2.49	0.013	-0.002	0.000		
EN	0.033***	0.009	3.56	0.000	0.015	0.052		
FDI	0.002	0.002	0.82	0.411	-0.002	0.005		
URB	0.001	0.001	0.55	0.583	-0.001	0.001		
ISU	-0.101	0.072	-1.40	0.160	-0.243	0.040		
GDP	0.042	0.093	0.45	0.653	-.140	0.223		
GDPP	-0.002	0.005	-0.37	0.712	-0.012	0.008		
Constant	-0.190	0.540	-0.35	0.724	-1.249	0.868		
Sargan	chi2 23.2533	P> chi2 0.9997	AR(1)	Z -1.8438	P> chi2 0.0652	AR(2)	Z 1.1567	P > chi2 0.2474
*** $p<0.01$, ** $p<0.05$, * $p<0.1$								

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The results of endogenous test are presented in table 5. The path coefficient of green economy efficiency lag phase one (L.EP) is significantly positive, which verifies the rationality of the research results and shows that the environmental pollution has a certain degree of accumulation. According to the regression results, AR (2) fails to pass the significance test, indicating that the second-order serial correlation of the random error term does not exist. Furthermore, Sargan test shows that the instrumental variables selected are valid. Thus, the regression results of this research are concluded to be reliable. As shown in table 5, the impact path of suppression of environmental pollution in China's provinces and cities by green technological innovation has declined (-0.077**VS-0.015**), but there is still a significant suppression effect. On the basis of this, the path of green technological innovation to the suppression of environmental pollution in China's provinces has not changed, further verifying the scientific nature of the conclusions of this study.

5 Threshold effect analysis

5.1 Threshold effect of R&D investment

Under the market environment, R&D investment is the source of green technology innovation output, which committed to the research and development of green production equipment and green

technology required by the society, and strengthened the ability to control environmental pollution in green technology innovation; LONG C(2011)believed that R&D investment through innovation compensation makes up for the market risk of the innovation subject, and reduces and corrects the market failure of green technology innovation, so that green technology innovation can meet the energy saving and emission reduction effects of enterprises. In addition, green technology innovation is used as R&D investment. The end product, R&D investment is the source of life for green technology innovation, which directly determines the depth and breadth of green technology innovation research, and then affects the suppression effect on waste pollution. Based on this, this study uses the logarithm of R&D investment as the threshold variable to explore the threshold effect of R&D investment on the suppression of provincial environmental pollution.

Table 6 Threshold effect test

Threshold value: R&D investment							
N	F	P	10%	5%	1%	门槛值	置信区间
1	28.630	0.084	27.497	32.981	45.184	14.574	14.485-14.604
2	15.290	0.342	23.718	28.407	36.791	15.311	15.276-15.339
Threshold value: Degree of marketization							
N	F	P	10%	5%	1%	门槛值	置信区间
1	24.900	0.134*	31.230	36.875	51.480	6.660	6.605-6.690
2	-0.470	1.000	26.606	32.265	41.714	6.820	6.780-6.840

As can be seen from Table6, considering the R&D investment as the threshold variable,the single threshold effect of R&D investment passes the 5% significance level, but the double threshold effect fails the significance test ($P=0.342$), and the single threshold value is 14.574. In addition, Figure 4 reports the relationship between the threshold estimate and LR. The confidence interval of the corresponding threshold value of 14.574 is [14.485-14.604], and the likelihood ratio is less than the critical value of 7.35 at the 5% level. Based on this, it can be considered as R&D The estimated value of the threshold effect of input is true, and the dual threshold effect is not significant, so I will not discuss it here.

Figure 4 The relationship between the estimated value of R&D investment and LR

Based on the threshold test, the panel threshold model is used to conduct regression analysis with innovation output as the threshold variable. The threshold effect test results show (see Table 7) that when R&D investment exceeds the single threshold value of 14.574, The path of green technological innovation inhibits environmental pollution was increased from -0.012 to -0.017, and passed the test at the 5% significance level, Accordingly that green technological innovation has a threshold effect of R&D investment in suppressing provincial environmental pollution. The reason lies in R&D investment, guiding the inflow of innovative elements, reducing R&D risks undertaken by innovation entities, increasing the output of green technology innovation, and strengthening the governance of provincial environmental pollution. It can be seen that R&D investment is an important support for regional green technology innovation to suppress environmental pollution, and the scientific matching of the two is the effective way to suppress regional environmental pollution. The research conclusion is for local governments and enterprises to formulate reasonable and scientific R&D investment to help green technology innovation Lay a theoretical foundation for development.

Table 7 Regression results of threshold effect

EP	β	SE	T	EP	β	SE	T
	R&D investment as a threshold variable				Degree of Marketization as a threshold variable		
ID	-0.002*	0.001	-1.890	ID	-0.002**	0.001	-2.830
EN	0.156***	0.030	5.130	EN	0.077**	0.031	2.450
FDI	-0.001	0.002	-0.130	FDI	-0.001	0.002	-0.010
URB	0.003**	0.001	2.380	URB	0.004***	0.001	4.070
ISU	0.005	0.084	0.060	ISU	-0.190**	0.079	-2.390
GDP	0.016	0.068	0.230	GDP	0.224***	0.062	3.620
GDPP	-0.003	0.003	-0.960	GDPP	-0.012***	0.003	-4.000
RDI<14.574	-0.012	0.008	-1.480	MD<6.660	-0.018**	0.008	-2.160
GT				GT			
RDI>14.574	-0.017**	0.008	-2.090	MD>6.660	-0.027***	0.009	-3.100
GT				GT			
trim(0.01 0.03) grid(100) bs(300 300)				trim(0.03 0.03) grid(300) bs(500 500)			
*** p<0.01, ** p<0.05, * p<0.1				*** p<0.01, ** p<0.05, * p<0.1			

5.2 Threshold effect of the degree of marketization

As the degree of marketization increases, inter-regional green innovation collaboration will deepen, promote the upgrading and transformation of green technologies, and promote the overall development of regional green through the spillover effects of green innovation, and contribute to ecological civilization At the same time, the optimal allocation of regional green innovation elements largely depends on the degree of marketization. Only when the degree of regional marketization is high, the availability and optimal allocation rate of regional innovation elements will be more reasonable, and the region will be improved. The green innovation system has strengthened the inhibitory effect of green innovation on regional environmental pollution. However, due to differences in factors such as regional economy-society-environment, there are certain differences in the degree of marketization in China's provinces, which affects the inhibitory effect of green innovation on regional environmental pollution. Based on this, in order to effectively promote the inhibitory effect of green innovation on regional environmental pollution, this study explores the threshold effect that green innovation may have the degree of market development under the synergy of the threshold model of Hansen(1999). A more scientific green innovation system helps regional environmental pollution control. The results are shown in Table6.

Figure 5. The relationship between the estimated threshold value of the degree of marketization

As can be seen from Table 6, considering the degree of marketization is used as the threshold, the single-threshold effect of the degree of marketization passes the 1% significance level test, but the double-threshold effect fails the significance test ($P=1.000$), so the degree of marketization has a single threshold effect, and its threshold value is 6.660. In addition, Figure 5 reports the relationship between the threshold estimate and LR. The confidence interval of the corresponding threshold value of 6.660 is [6.605-6.690], and the likelihood ratio is less than the critical value of 7.35 at the 5% level. Based on this, it can be considered that the market threshold effect of the degree of transformation is true and reliable, and the dual-threshold effect is not significant, so I will not discuss it here.

Based on the threshold test, the panel threshold model is used to conduct regression analysis with the degree of marketization as the threshold variable. The threshold effect test results show (see Table 5.12) that when the degree of marketization exceeds the threshold value of 6.660, the path coefficient of its action increases from -0.018 to -0.027, and passes the 1% significance level, it can be seen that when the regional marketization reaches a higher level of development, green innovation can more significantly inhibit regional environmental pollution. This is consistent with the hypothesis 4 in the article, that is, green innovation has a significant marketization threshold effect in the process of restraining regional environmental pollution. The reason is that, with the development of provincial marketization, the circulation of regional innovation factors has accelerated, and the rate of optimized allocation of innovation factors has been effectively improved, which helps the coordinated advancement of regional green innovation, strengthens green innovation output, and enhances the suppression effect of environmental pollution. The intensity of marketization is an important support point for regional green innovation to suppress environmental pollution. The scientific matching of the two is an effective way to suppress environmental pollution in China's provinces. The suppression effect of pollution lays a theoretical foundation.

6 Analysis of Transmission Mechanism

Green technological innovation has inhibitory effects on environmental pollution in China's provinces, but green technological innovation does not directly achieve the effects of inhibiting environmental pollution. It needs to be realized with the help of intermediary bridge variables to realize the "curve overtaking" of environmental pollution control; for scientific verification The path of green technological innovation to the suppression of environmental pollution in China's provinces. In this paper, energy consumption structure (coal consumption proportion) and industrial structure upgrading are selected as intermediary variables to clarify that energy consumption structure and industrial structure upgrading are in the process of green technological innovation in suppressing environmental pollution. The mechanism of action, the analysis results are shown in Table 8 and Table 9.

6.1 Transmission Mechanism one: industrial structure upgrading

As shown in Table 8, M2 shows that the effect path of green technology innovation on industrial structure upgrading is 0.049, passing the significance test at the 1% level; adding industrial structure upgrading variables on the basis of the M1 model, formation the M3, it can be seen from M3 that after adding the intermediary variables industrial structure upgrade, the suppression path of green technology innovation on environmental pollution decreases from -0.079** of M1 to -0.077***, which shows that the upgrading of industrial structure plays an intermediary conduction effect in the process of green technological innovation to suppress environmental pollution, but the intensity of intermediary conduction is not ideal. The reason lies in the fact that green technological innovation is integrated into green concepts to increase the added value of green technology in products, promote the extension of the industrial chain, and promote the upgrading of industrial structure; at the same time, green technological innovation can change the traditional innovation system and derive emerging industries by promoting the development of green products and green industries. , To promote the upgrading of the industrial structure to achieve the goal of curbing China's provincial environmental pollution, but at this stage, affected by the traditional economy and traditional industries, the upgrading of China's provincial industrial structure is not ideal, and there is still a long way to go.

Table 8 Tests on mediating effect of industrial structure upgrading

	M1:EP		M2:ISU		M3:EP	
	β	T	β	T	β	T
GT	-0.079***	-5.730	0.049***	7.130	-0.077***	-5.230
ISU					-0.049	-0.460
ID	-0.002**	-2.380	-0.005***	-11.400	-0.002**	-2.300
EN	0.358***	16.690	0.034***	3.210	0.353***	15.480
FDI	0.010***	2.900	-0.002	-1.060	0.010***	2.740
URB	-0.001	-1.310	0.006***	20.860	-0.001	-0.620
GDP	-0.503***	-5.970	-0.244***	-5.800	-0.505***	-5.690
GDPP	0.025***	5.910	0.009***	4.430	0.026***	5.820
w*GT	-0.027	-1.260	0.050***	4.500	-0.033	-1.380
w*ISU					0.127	0.860
w*ID	-0.001	-1.100	0.001	0.310	-0.001	-0.440
w*EN	0.136***	2.930	0.092***	5.440	0.137***	2.880
w*FDI	0.007*	1.600	0.007***	3.100	0.008*	1.680
w*URB	0.004***	4.990	0.001**	2.740	0.003**	2.700
w*GDP	0.196*	1.470	-0.192***	-2.890	0.223**	1.580
w*GDPP	-0.013*	-1.920	0.002	0.550	-0.014**	-2.040
ρ	0.208***	3.480	-0.044	-0.800	0.205***	3.430
R-sq	0.865		R-sq	0.911	R-sq	0.874
Log-L	358.287		Log-L	614.328	Log-L	358.786

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

6.2 Transmission mechanism 2: Energy consumption structure

As shown in Table 9 M2 shows that the path of action of green technology innovation on energy consumption structure is -0.006***. Through the significance test, it can be seen that green technology innovation can reduce coal consumption, optimize the structure of energy consumption ; On the basis of the M1 model, M3 is formed after adding the energy consumption structure. Model 3 shows that the suppression path of green technological innovation on environmental pollution has dropped from 0.077 to 0.075. It can be seen that the energy consumption structure plays an important role in the suppression of environmental pollution by green technology innovation. In the process, it acts as an intermediary bridge, which is consistent with the upgrading of the industrial structure, and the intermediary transmission strength is insufficient. The possible reason is that green technological innovation can promote the clean use of traditional fossil fuels, improve technical support for the development of new energy such as wind, solar, and geothermal, increase the proportion of new energy consumption, reduce the proportion of traditional fossil fuel consumption such as coal, and promote the optimization of energy consumption structure , To achieve the goal of restraining environmental pollution in China's provinces, but limited by the traditional energy consumption structure and the current level of green technology innovation and development, the upgrading of energy consumption structure is not ideal, and it is not enough to become one of the core elements of restraining regional environmental pollution. Its optimization and upgrade path still has a long way to go.

Table 9 Tests on mediating effect of **Energy consumption structure**

VAR	M1:EP		M2:NY		M3:EP	
	β	T	β	T	β	T
GT	-0.077***	-5.230	-0.006*	-2.560	-0.075***	-5.120
NY					0.110*	1.640
ID	-0.002**	-2.300	0.006***	7.470	-0.003**	-2.730
EN	0.353***	15.480	0.150***	8.590	0.324***	13.020
FDI	0.010***	2.740	0.008***	2.540	0.002	0.480
URB	-0.001	-0.620	-0.007***	-11.090	0.001	0.890
ISU	-0.049	-0.460	0.404***	4.900	-0.133	-1.230
GDP	-0.505***	-5.690	0.565***	8.180	-0.598***	-6.220
GDPP	0.026***	5.820	-0.037***	-10.760	0.032	6.300
w*GT	-0.033	-1.380	-0.023	-1.250	-0.019	-0.790
w*NY					0.437***	3.100
w>ID	-0.001	-0.440	0.001	0.330	-0.002*	-1.940
w*EN	0.137***	2.880	-0.028	-0.940	0.085*	1.640
w*FDI	0.008**	1.680	0.026***	7.420	0.001	0.250
w*URB	0.003**	2.700	-0.003***	-2.550	0.006***	4.010
w*ISU	0.127	0.860	0.136	1.180	0.096	0.650
w*GDP	0.223*	1.580	0.339***	2.960	-0.073	-0.450
w*GDPP	-0.014**	-2.040	-0.015***	-2.530	0.002	0.290
ρ	0.205***	3.430	-0.015	-0.220	0.194***	3.230
R-sq	0.865		R-sq	0.856	R-sq	0.868
Log-L	358.287		Log-L	453.874	Log-L	364.726

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

7. Conclusion and Enlightenment

7.1 Conclusion

Based on the background of the new normal of the construction of a beautiful China, the paper uses the time dimension from 2008 to 2019 and 30 provinces and cities in China as the research objects. Using spatial measurement and other methods to focus on the relationship between green technological innovation and environmental pollution;Controlling the threshold effect of green technological innovation on the suppression of environmental pollution;Clarify the mediation effect of green technological innovation in the process of suppressing environmental pollution, Research indicates:

(1)Direct effect: Green technological innovation guides the green production of enterprises, improves the comprehensive utilization rate of resources and energy in the production process, reduces the resource and energy consumption rate per unit output, reduces pollution emissions, and achieves the inhibitory effect on provincial environmental pollution; On the basis of considering endogenous issues, the path of green technological innovation to inhibit environmental pollution in China's provinces has not changed, further verifying the scientific nature of the conclusions of this study.

(2)Threshold effect: Green technological innovation has a threshold effect of environmental regulations and R&D investment on regional environmental pollution. Environmental regulations and R&D investment are within a reasonable threshold. Green technological innovation has a more significant effect on provincial environmental pollution suppression.

(3)Mediation effect: Green technological innovation has an intermediary effect of industrial structure and energy consumption structure in the process of restraining regional environmental pollution, but the intermediary effect is not ideal, and there is a greater degree of correlation with the current green innovation, industrial structure upgrade, and energy consumption structure matching.

The research conclusions further expand the path of green technological innovation to contain environmental pollution, and can provide reference for local governments in environmental pollution control.

7.2Enlightenment

(1) Strengthen green technological innovation and help regional environmental pollution control.

Local governments should aim for high-quality economic development and support the five development concepts, increase financial subsidies and preferential tax policies for enterprises, guide enterprises to invest funds, promote industrial green technological innovation, optimize industrial structure and energy consumption structure, and help regions Environmental pollution. In addition, regional environmental governance should break its own traditional governance model, accurately track the direction of green technology innovation, build regional provinces and cities joint prevention and control mechanisms, and jointly formulate green technology innovations to suppress environmental pollution and provide regional environmental pollution. Govern energy efficiency and share the effectiveness of environmental governance of green technological innovation.

(2) Define the threshold value for green technological innovation to restrain environmental

pollution. Provincial governments should consider the degree of marketization and R&D investment, and appropriately adjust market supervision policies based on the level of regional market development to promote market-oriented development; introduce green technology innovation system development policies to support and consolidate investment in the green technology innovation system, and avoid R&D Insufficient investment has weakened the suppression of environmental pollution caused by green technological innovation, while improving laws and regulations on the protection of environmental protection rights, eliminating the concept of strong government and weak market, consolidating green methods, curbing regional environmental pollution, and improving regional economic high-quality growth.

(3) Clarify the intermediary conduction effect of energy consumption structure and industrial structure upgrade:strengthen green innovation, accelerate the development of green industries and emerging industries, and promote the upgrading of industrial structure; in addition, use the advantages of green technology to increase wind energy and electric power , Solar energy and other new energy sources, reduce the proportion of coal and other traditional fossil fuel consumption, promote the optimization of energy consumption structure, and continue to promote the performance of China's provincial environmental pollution control.

Declarations

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

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