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Original Paper

Research on Green Process Innovation Enabling the Synergistic Effect of Pollution Reduction and Carbon Reduction

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Abstract

Achieving the objective of "peak carbon dioxide emissions and carbon neutrality" in the new stage of development will require the synergistic effect of pollution reduction and carbon reduction. In the new stage of development, achieving the goal of "peak carbon dioxide emissions and carbon neutrality" will necessitate the synergistic effect of pollution reduction and carbon reduction. This study assesses the degree to which pollution reduction and carbon reduction have a synergistic effect using the coupling coordination model, and uses the fixed effect model, the dynamic panel GMM model, the OLS model and the threshold effect model to examine how green process innovation affects pollutant reduction and carbon reduction synergistically, including direct, heterogeneous, and nonlinear effects. The results show that: firstly, green process innovation has a direct promoting effect on synergistic effect of pollution reduction and carbon reduction; Secondly, due to the differences in the economic development of different regions in China, the impact of green process innovation on the synergistic effect of pollution reduction and carbon reduction is heterogeneous in different regions, and presents a gradient distribution of "east > west > middle". Finally, there is a threshold effect in the impact of green process innovation on regional synergistic effect of pollution reduction and carbon reduction. This paper provides some reference value for promoting green process innovation and enhancing the collaborative impact of mitigating pollution and decreasing carbon emissions.

Keywords

green process innovation, synergistic effect of pollution reduction and carbon reduction, benchmark regression, heterogeneity analysis, threshold effect

1. Introduction

Present-day global warming has surpassed prior warming by 1.45±0.12°C versus pre-industrial levels. As the world's largest producer of carbon emissions and consumer of energy (Guo, 2021; Cheng, 2021), China's environmental governance is crucial to achieving the goal of a "green earth". As the largest contributor to global carbon emissions and the foremost consumer of energy in the world, that is, the synergistic effect of pollution reduction and carbon reduction (hereinafter referred to as Combined). Confronted with the dual goals of pollutant and greenhouse gas emission reduction, and (2022; 2023) both put forward the goal of promoting to achieve "Pareto optimum". As a large developing industrialized country, China's environmental protection is facing structural, root cause and trend pressures, however, these pressures have not been fundamentally alleviated on the whole. Therefore, the task of realizing is still very difficult.

With the increasingly serious problems of global climate change and environmental pollution, green process innovation (hereinafter referred to as Green) has emerged as a crucial avenue for enterprises to accomplish sustainable development and enhance competitiveness. Through Green, enterprises can reduce energy consumption, reduce waste emissions and improve resource utilization efficiency in the production process, so as to achieve a win-win situation of economic and environmental benefits (Xie et al., 2021). is an important means to encourage both green development and the modernization and transformation of the economy. With the backdrop of worldwide environmental issues becoming more and more evident, it is fundamental both theoretically and practically to advance Green. China urgently needs to seize the mainstream advantage of green economic development, inject continuous power into the Combined, so as to break the double threats of air pollution and climate change, and solve the two problems of pollution reduction and carbon reduction. In this process, is likely to play an important role (Wang et al., 2021). However, although the development prospects of are promising, the relationship between and has not been fully studied and verified.

Therefore, a practical question worth thinking about is: can promote the Combined? If so, what is the transmission mechanism? At the same time, considering the heterogeneity of different regions in China, does present unique action rules and characteristics on the in different regions? This paper intends to answer the above questions and provide a feasible path for China's to enable Combined. The remainder of this work is structured as follows after the introduction: the influence of and the Combined, and the appropriate research on are investigated in the second section. The paper's theoretical analysis and research hypothesis are expounded upon in the third section. The data source, the constructed model, and the measurement of relevant variables are all introduced in the fourth section; In the fifth section, the empirical results of this paper are comprehensively analyzed. Finally, we draw the main conclusions, propose policy recommendations, and look forward to the future.

2 Literature Review

2.1 Relevant Research on Green Process Innovation

Green will become one of the effective means to prevent environmental pollution and stimulate the establishment of the new industrial sector, which is essential to the accomplishment of sustainable, green development. Currently, there are few researches focusing on Green, and the relevant researches mainly focus on three aspects: connotation definition, measurement and driving factors.

Definition of connotation. The academic community has a unified definition of *Green*. Based on the studies of scholars such as Chen (2008) and Xie (2016), green process innovation mainly refers to an innovation model that reduces the negative impact on the environment by improving existing or new production processes. It is mainly subdivided into two dimensions: cleaner production technology and end-treatment technology (Xie et al., 2016; Hammar et al., 2010), respectively improving the source and end processes to reduce pollution generation. Many scholars mainly study Green from closely related fields such as enterprise and manufacturing industry, and define Green in different fields according to different research directions and their own concepts. Yang and Tian (2019) believe that Green in manufacturing industry is not only a component of green innovation in manufacturing industry, but also a branch of process innovation in manufacturing industry. Xie et al. (2019) mentioned that Green refers to the innovation mode in which manufacturing enterprises use new or improved processes to reduce the impact of production activities on the environment.

(2) Variable measurement. Most scholars build a multi-index comprehensive evaluation system to study green technology, which is mainly subdivided into two dimensions. In terms of cleaner production technology, scholars measured the intensity of pollution generation (Bi et al., 2011), energy efficiency, use of recycled materials, recycling processes, environmental protection processes or technologies (Zeng et al., 2011), and the ratio of regional SO_2 production to local GDP (Liu & Wang, 2013). In terms of end-treatment technologies, the measurement methods mainly include the ratio of pollution generation to output value (Fujii et al., 2013), the comprehensive use of pollution monitoring and treatment facilities, and the degree of implementation of pollution treatment technology (Jin et al., 2022). Another part of scholars tend to use a single indicator to measure Green. Wang and Guo (2016) mentioned that Green can be measured through green transformation of production process, green upgrading of process technology and effective disposal and recycling of "three wastes". Therefore, the ratio of technological transformation funds input to industrial added value was adopted to measure Green. Yang and Tian (2019) believe that the number of patents can well reflect the technological innovation achievements of an industry, and choose the number of green process patents in the manufacturing industry to measure it.

(3) Riving factors. External and internal factors work together to make Green produce different effects in different contexts. From the external perspective, it mostly manifests itself in the various ways that the government, system, and external stakeholders. Based on the viewpoints of scholars such as EI-Kassar et al. (2019) and Wang et al. (2017) the guiding role of stakeholders such as consumers,

investors and competitors in enterprises' *Green* practice is explored. From the internal point of view, technology, knowledge integration ability and other aspects affect Green. The so-called technical level mainly alludes to the advancement of end-treatment and cleaner production technologies; Xue et al. (2016) believe that the vertical networking ability and proprietary technology integration ability of external knowledge integration ability have a significant positive impact on the Green ability.

2.2 Research on the Impact of Green Process Innovation

As one of the dimensions of green innovation, is crucial. Most of the impact effects focus on the positive effects, mainly reflected in environmental performance, financial performance, social performance. Green can effectively improve energy utilization rate and reduce waste generation rate through the use of alternative energy, process improvement and resource recycling, and ensure that the production and manufacturing processes of enterprises comply with environmental regulations, thus avoiding environmental pollution penalties (Yu et al., 2017). From the perspective of environmental performance and social performance, according to the studies of Guo (2017) and Huang (2017) and other scholars, the adoption of Green by enterprises can significantly improve the ability of enterprises to abide by environmental laws, cut back on pollutants, and boost energy conservation. In the long run, increased investment in cleaner production technology innovation can not only reduce negative environmental impacts, but also reduce costs by accelerating innovation, which leads to positive effects on financial performance; Although the innovation practice of end-management technology is accompanied by an increase in cost, it will still have a positive impact on financial performance (Xie et al., 2019). At the same time, cleaner production technologies and end-treatment technologies can help enterprises break through resource constraints more effectively to meet the government's requirements for energy conservation and emission reduction, thus better improving environmental and social responsibility performance (Xie & Zhu, 2021). Green has contributed positively to improvement of the social, financial, and environmental performance of the region. By means of granting acceptance of Green, not only can reduce environmental pollution, improve resource utilization efficiency, but also enhance their own sense of social responsibility, and achieve efficiency improvement at the financial level. Therefore, Green has become a key means for enterprises to achieve sustainable development and fulfill their environmental protection responsibilities. has brought significant positive impacts to enterprises and society in many aspects, however, any change may be accompanied by certain challenges and potential adverse effects. First, Ngniatedema et al. believe that Green will bring additional cost burden to enterprises, and its realization needs to adopt more environmentally friendly and energy-saving production technologies and processes, and the research and development and application of these technologies often require a higher technical level and investment, which is not conducive to improving financial performance; Second, the market must go through a certain process of adaptation and acceptance prior to green technology is able to truly transform, which may have a certain impact on sales and market share. Therefore, while Green brings benefits to the region, it also has potential risks.

2.3 Relevant Research on the Combined

The concept of synergy was first proposed by the famous physicist Hermann Haken, which was mainly applied in the field of natural sciences. The research on the originates from the intersection of the synergy effect and the field of public environmental governance. Existing studies have confirmed the promoting effects of energy-saving technology progress, energy structure transformation and financial inclusion on pollution reduction or carbon reduction. Coordinated efforts to reduce pollution and carbon will have a positive impact on improving residents' health benefits, reducing the total emission reduction cost of the whole society and promoting industrial green transformation.

Based on the above research, there is still room for improvement in the research between Green and Combined. Second, significant regional heterogeneity has not been fully considered in the research on innovation in technology, decrease of pollutants, and reduction of carbon. Third, the previous studies lacks the integration of Green and into the same framework to explore the complex nonlinear effects between the two.

Different from previous studies, this paper is committed to exploring the multi-dimensional impact of Green on the Combined, which may make the following three marginal contributions. Firstly, this paper explores the deep-level relationship between Green and the Combined, and verifies the impact of Green on the from an empirical perspective. Secondly, based on the reality of unbalanced regional development, this paper explores the heterogeneity of the Green and Combined. Thirdly, this paper takes Green itself as the threshold variable to examine its nonlinear impact on the Combined, so as to clarify the theoretical and practical references for accelerating Green and realizing Chinese-style green modernization development.

3. Mechanism Analysis and Research Hypothesis

3.1 Baseline Regression Analysis

Green is an important strategy for realizing regional sustainable development goals (Huang & Li, 2017). For a long time, a major challenge in the process of implementing the sustainable development strategy in China is how to improve the environmental efficiency while achieving the goal of sustainable development. The fundamental reason is that China's original "high input, high consumption, high pollution" extensive mode of economic growth has not been fundamentally changed, if only the use of the traditional "pollution first, then treatment" mode, can not effectively control industrial pollution. Therefore, it is urgent to seek the improvement and innovation of production process, and pollution control from the source and end has become an important measure to achieve green production and reduce pollution and carbon.

On the one hand, as the frontier of technological innovation, Green has the characteristics of high risk and high cost (Cao & Chen, 2017). From the source, cleaner production technology emphasizes minimizing or preventing the production process's advancement and emission of pollutants, service and product use (Huang & Li, 2017), including the use of alternative energy, environmentally friendly materials and resource recycling, etc. It proposes environmentally friendly and low-carbon guidelines for the entire of industrial chain, the entire production process, and the entire product life cycle. Assisting the modernization and transformation of the low-carbon, green industrial structure is desirable. At present, there are three ways to achieve green innovation in process innovation: developing new process technology to enable clean energy to be used in production (Zhong & Wang, 2000). Clean technology can reduce pollutant emission and carbon emission by adopting efficient and environmentally friendly production methods, promote resource recycling, reduce carbon footprint of the entire economic system, and promote sustainable development.

On the other hand, end-treatment technology focuses on transforming pollutants into other substances that are easier to deal with in order to lower carbon emissions and pollutant discharges after production (Frondel et al., 2007). End-treatment technology has a direct impact on pollution and carbon reduction. The successful practice of end-treatment technology contributes to the preservation of ecosystems and biodiversity, as well as the quality of the water, soil, and air. At the corporate level, they can help companies meet regulatory requirements and avoid penalties for excessive emissions of pollutants and carbon. In terms of pollution reduction and carbon reduction management measures, industry scale control and symbiotic technology promotion measures contribute more to the realization of energy conservation goals, while the promotion of end-treatment technology has a better effect on the reduction of nitrogen oxides and smoke dust. The combination of the two will enable the regional pollution reduction and carbon reduction goals to be efficiently completed (Ye et al., 2022), and maximize environmental and economic benefits.

In summary, under the background of "dual carbon", Green reduces carbon and pollutant emissions through source clean technology and end treatment technology, and achieves Combined.

H1: *Green* can directly promote the Combined.

3.2 Heterogeneity Analysis

The eastern region has a more developed economy and a higher technological endowment, with more advanced energy mining and utilization technologies and the support of related industrial chains, and is more perfect in environmental protection policies and measures for Combined. can produce more significant effects on the Combined. However, due to the relatively small market demand in the middle region and the backward economic development in the western region, the environmental governance system has not been improved, which makes it difficult for enterprises to gather and form "scale effect" to drive the in (Chen et al., 2020). Therefore, different regions have different levels of economic development, policies and governance systems, which may lead to unbalanced investment in Green, thus affecting the process of Combined.

H2: The realistic background of unbalanced regional economic development in China will lead to heterogeneity in the in promoting Combined.

3.3 Threshold Effect Analysis

Based on the externality of environmental governance and the significant regional heterogeneity in various regions of China, is likely to have a nonlinear impact on the Combined. According to the theory of technological innovation, when the level of is low, the proportion of high-polluting industries is too large, based on the consideration of profit maximization, enterprises have insufficient motivation to reduce emissions, pollutants and carbon emissions cannot be effectively controlled, and the effect of relying on to promote the is limited (Li et al., 2023). From the perspective of innovation economics and environmental economics, not only has the traditional innovation characteristics such as high-value novelty, but also has the advantage of using clean energy technology to improve environmental quality and enhance the degree of (Saunila, 2018).

H3: The impact of on the has nonlinear characteristics, and the positive impact is more significant when the level of is higher.

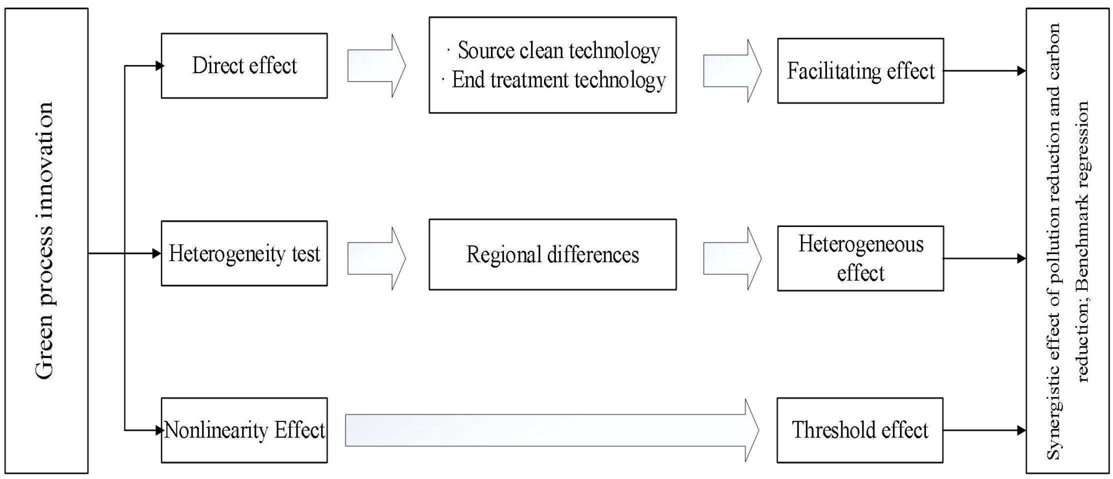

Figure 1. Theoretical Framework of Affecting the Combined

4. Research Design

4.1 Model Construction

The present investigation applies the fixed effect model and the threshold effect model to investigate both direct and nonlinear impacts of on the respectively in order to test the three hypotheses put forth.

4.1.1 Benchmark Regression Mode

$$\mathbf{Combined}_{it} = \alpha_0 + \alpha_1 \mathbf{Green}_{it} + \alpha_n X_{it} + \lambda_i + \varepsilon_{it} \quad (1)$$

Where, and are the province and year respectively, represent the synergistic effect of pollution reduction and carbon reduction, are the core variables of this paper, represent green process innovation, and represent the control variables in the model, including four types of variables: education level (hereinafter referred to as Education), urbanization level (hereinafter referred to as City), population density (hereinafter referred to as Population) and industrial enterprise scale (hereinafter referred to as Unit). In addition, Equation (1) represents the intercept term, which constitutes an unobservable individual fixed effect and indicates the random disturbance term.

4.1.2 Threshold Effect Model

In addition, The panel threshold regression model is employed in the current investigation to assess the threshold effect between and Combined.

$$Combined_{it} = \mu_i + \theta_1 Green_{it} \cdot I(threshold_{it} \le \gamma) + \theta_2 Green_{it} \cdot I(threshold_{it} > \gamma) + \theta_n X_{it} + \varepsilon_{it} \quad (2)$$

Where represents the threshold variable in this paper, is the threshold value, is the indicator function, the value is 1 if the corresponding conditions are true, otherwise it is 0, and the remaining variables are the same as Equation (1).

4.2 Variable Measurement

4.2.1 Explained Variable

Considering that the emission of air pollutants and carbon dioxide have the characteristics of the same root, same origin and same process, the is feasible. In this paper, in terms of pollution reduction, the emission of carbon dioxide, soot and nitrogen oxide is mainly selected for measurement. Emissions of carbon dioxide are selected for monitoring in terms of carbon reduction. Things' coordinated development level is examined employing the coupling coordination model, and the interaction and influence between two or two systems can be represented by the coupling degree. Therefore, the evaluation of the is studied by using the coupling coordination model, and then the differences in the synergy degree between air pollutant emission control and carbon emission reduction in different regions are analyzed. Referring to the research method of Han et al. (2023), this paper divides the levels of coupling degree and coupling coordination degree, and redefines the model, and obtains the following model calculation method:

$$C = \frac{2\sqrt{U_1 U_2}}{U_1 U_2} \quad (3)$$

$$T = aU_1 + bU_2 \quad (4)$$

$$Combind = \sqrt{C \times T} \quad (5)$$

Where, is pollutant emissions, is carbon emissions, this paper adopts the range standardization method to carry out dimensionless processing of the index; is the coupling coordination degree, and the value is [0,1]. The greater the value of Combined, the better the coordination between pollutant emission control and carbon emission reduction systems, and the stronger the degree of coordination; The smaller the value of Combined, the worse the coordination between the two systems of pollutant emission control and carbon emission reduction is, and the weaker the degree of coordination is.

represents the coupling degree of two systems; is the comprehensive coordination index of the two systems; and are the specific gravity, with reference to the research of Wang et al. (2021), this paper takes $a=b=0.5$, which means that reduction of carbon dioxide emissions and air pollution emission control are equally important.

4.2.2 Core Explanatory Variables and Threshold Variables

Green: The focus of is mainly on the research and development or transformation and upgrading of production process equipment. Referring to the research of Wang et al. (2018), this paper uses the sum of internal R&D expenditure and technological transformation investment to represent it.

4.2.3 Control Variables

The is a complex and systematic project, in addition to the core explanatory variable of Green, this paper selects other control variables to be included in the model, as shown below: ① Education. Referring to the research of Han et al. (2023), it is represented by the number of students in colleges and universities per 100,000 people. ② City. There is a high correlation between China's and carbon emissions and pollutant emissions, which is an important perspective to study the Combined. ③ Population . Referring to the article of Alaimo et al. (2023), the is used as a control variable. has a certain correlation with energy consumption and pollutant emissions; ④ Unit. With reference to the article of Guo et al. (2023), the number of industrial enterprises above designated size is included in the control variable. The larger the scale of industrial enterprises is, it will have an impact on industrial technology innovation, industrial aggregation degree and so on, thus affecting carbon emissions.

4.3 Data Source and Descriptive Statistics

In this paper, 30 provinces in China from 2011 to 2020 are selected as the research samples, since the data of Hong Kong, Macao, Taiwan and Tibet in China are obviously missing, we have eliminated them. The data come from the China Statistical Yearbook and other public materials of the National Bureau of Statistics. In order to improve the accuracy and credibility of estimation and avoid heteroscedasticity and multicollinearity, this paper takes the logarithm of relevant variables, and uses the linear interpolation method to fill in the missing data of some years in the region.

The correlation coefficient matrix between the variables utilized in this paper is displayed in Table 1. It can be seen from the table that the correlation coefficient between and is 0.519, indicating that there is a certain positive correlation between and Combined, which also preliminarily verifies the conclusion of this paper. In addition, the results of the correlation coefficient matrix show that there is no large correlation between the variables, which alleviates the concern of collinear problems in the regression model to a certain extent, so the subsequent regression analysis can be carried out.

Table 1. Correlation Matrix and Descriptive Statistics of Each Variable

	Combined	Green	Education	City	Population	Unit
Combined	1.000					
Green	0.519***	1.000				
Education	0.446***	0.105*	1.000			
City	0.393***	0.256***	0.733***	1.000		
Population	0.689***	0.272***	0.653***	0.574***	1.000	
Unit	0.904***	0.435***	0.256***	0.194***	0.570***	1.000
N	300	300	300	300	300	300
Mean	1.844	0.028	7.837	0.583	5.470	8.833
SD	0.512	0.078	0.285	0.122	1.290	1.194
Min	0.362	1.48e-06	6.987	0.350	2.062	5.814
Max	2.963	0.665	8.633	0.960	8.275	10.976

5. Empirical Results and Analysis

5.1 Analysis of Benchmark Regression Results

Table 3 reports the results of the direct impact of on the Combined. Under the test of the three categories of models, demonstrates a considerable improvement on the Combined, which confirms hypothesis 1 of this paper. Model (1) shows that the coefficient of on the is 0.062, which is relatively significant. According to Model (2), after the introduction of the lagged term of the explained variable, still plays a significant role in promoting the Combined, with an influence coefficient of 0.020 and passing the 1% significance test. The OLS test of Model (3) also shows that 1% has a significant promotion effect, with a coefficient of 0.090. It can promote the innovation and progress of energy technology, improve the efficiency of energy use, reduce energy consumption and pollutant emissions, achieve green, efficient, safe and low-carbon development of energy, and thus boost the Combined

Regarding the variables beneath control, the effect coefficient of on the is 0.203, which is significant at the level of 5%. It shows that the higher Education, the stronger awareness of environmental protection and sustainable development of the population, is more conducive to the Education. For every unit change in urbanization level, the synergy index of pollution reduction and carbon reduction will change by 1.965 units. drives rural population mobility, promotes the increase of rural vegetation cover and biomass, improves the stability and sustainability of ecosystem, and accelerates the process of Combined. promotes the in the whole country at the significance level of 10%. The will be supportive of the agglomeration effect and the initiatives to minimize carbon emissions and pollution can be planned and implemented in a coordinated manner, which is conducive to the Combined. The coefficient of the impact of the Unit on the is 0.090, which is significant at the level of 5%, thus enabling the Combined.

Table 2. Benchmark Regression Results

	(1)	(2)	(3)
	FE	GMM	OLS
L. Combined		0.797***	
		(0.012)	
Green	0.062**	0.020***	0.090***
	(0.026)	(0.006)	(0.034)
Education	0.203**	0.003	0.122**
	(0.082)	(0.018)	(0.060)
City	1.965***	-0.014	0.369**
	(0.210)	(0.042)	(0.145)
Population	0.379*	0.009***	0.040***
	(0.230)	(0.002)	(0.015)
Unit	0.090**	0.046***	0.260***
	(0.036)	(0.004)	(0.033)
_cons	-4.669***	-0.360***	-3.172***
	(1.053)	(0.111)	(0.451)
N	300	270	300

***$p < 0.1$, **$p < 0.05$, ***$p < 0.01$ (the same below).**

5.2 Analysis of Heterogeneous Results

According to Models (4)-(6), it can be obtained that the impact of on the presents a trend of "east > west > middle". This paper holds that the main reasons are as follows: on the one hand, the eastern region has a more developed economy, The consolidation of businesses drives the growth of the Green, and a greater role in the can be contributed through transforming the structure of energy consumption to one that is clean and low-carbon; On the other hand, although the western region has a strong endowment of solar energy, wind energy and other natural resources, due to the relatively remote geographical environment and scattered location of enterprises, it is difficult for enterprises to gather to form "economies of scale". The development speed of to drive is relatively slow, while the market demand in the central region is relatively small. Moreover, resources and other factors have limited space for the dividend of Combined. To sum up, there is heterogeneity in in promoting in different regions, and hypothesis 2 is established.

Table 3. Results of Regional Heterogeneity Test

	(4)	(5)	(6)
	East	Middle	West

Green	0.116***	0.050*	0.100*
	(4.69)	(1.75)	(1.75)
Education	0.045	0.216*	0.092
	(0.73)	(1.73)	(0.57)
City	0.789***	1.271***	3.594***
	(5.44)	(4.08)	(7.26)
Population	0.517***	-0.288	1.161
	(2.89)	(-0.94)	(1.64)
Unit	0.008	0.269***	-0.217**
	(0.33)	(5.59)	(-2.23)
_cons	-3.981***	-2.105	-5.765**
	(-4.28)	(-1.42)	(-2.30)
N	110	80	110
R^2	0.782	0.899	0.896

5.3 Analysis of Threshold Effect Results

According to the methods mentioned above, this paper tests the panel threshold model with as the threshold variable, that is, the following three sets of hypothesis tests are carried out respectively: ① there is no threshold; ② There is a threshold; ③ There are two thresholds. Table 4 illustrates the test results assuming repeated Bootstrap sampling., the has been accomplished by passing the significance test at the 10% level for the single threshold effect, while the double threshold has not passed the test with the threshold value of 13.5814, which confirms the research hypothesis 3 proposed in this paper.

Table 4. Test Results of Threshold Effect

Threshold	value of F	Value of P	Threshold value	Number of BS	Critical value		
					10%	5%	1%
Single threshold	23.900	0.080	13.5814	300	22.430	32.097	42.973
Double threshold	19.340	0.233		300	25.105	27.704	34.287

Secondly, in order to more clearly observe the estimation results of the threshold and the corresponding 95% confidence interval, this paper uses the least squares likelihood ratio statistic LR to identify the threshold. The likelihood ratio function of itself as the threshold value is depicted in Figure 2. Therefore, based on the threshold heterogeneity interval, it can be divided into two types: low (Green≤13.5814) and high (Green>13.5814).

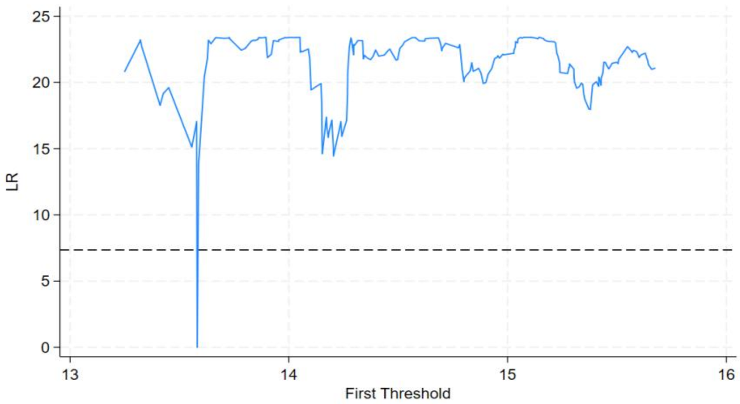

Figure 1. Plot of the Likelihood Ratio Function of each Threshold Variable: Green Process Innovation

The results in Table 5 show the model estimation results when is used as the threshold variable. As crosses the threshold value of single weight, the positive impact of on the is gradually strengthened. When the is less than 13.5814, the positive effect coefficient of on is 0.043; when the is greater than 13.5814, the influence coefficient of on gradually increases to 0.050. With the continuous improvement of Green, the collaborative treatment of pollutants and carbon emissions has been widely carried out in various regions, and advanced technologies have been adopted to effectively reduce energy consumption costs and improve energy efficiency. In this process, the positive role of on has been fully brought into play.

In general, under the constraint of taking itself as the threshold variable, it has a significant nonlinear promotion effect on the Combined, which further strengthens the research conclusion of this paper and coincides with the results of existing scholars, hypothesis 3 is proved.

Table 5. Estimation Results of Model Parameters

Parameters	Coef.	Std. Err	t	p＞|t|	95% Conf. Interval	
Population	0.203	**0.081**	**2.50**	**0.013**	**0.043**	**0.362**
City	1.951	**0.209**	**9.35**	**0.000**	**1.540**	**2.362**
Population	0.414	**0.228**	**1.81**	**0.071**	**-0.036**	**0.863**
Unit	0.085	**0.036**	**2.37**	**0.019**	**0.014**	**0.156**
Green·I （threshold≤γ）	0.043	0.027	**1.55**	**0.122**	**-0.011**	**0.096**
Green·I （threshold≥γ）	0.050	0.027	**1.88**	**0.062**	**-0.002**	**0.102**

5.4 Robustness Test

In order to examine whether the results are robust, this paper conducts robustness tests through three methods: lagged one period of core explanatory variables, adding control variables and reducing control variables. First of all, considering the time-lag of the Combined, this paper takes the lagged by one year as a new explained variable. Secondly, by adding the control variable of environmental regulation for testing, the coefficient is similar to the research results, which verfies the robustness of the model results in this paper. Finally, this paper draws on the robustness test method of Sun and Deng (2022) to conduct the robustness test of reducing control variables, the analysis shows that still has a significant positive impact on Combined. It is consistent with the basic regression results, which proves that the results of this paper are robust.

Table 6. Robustness Test

	(10) L.Coordination	(11) Add variable	(12) Reduce variable
Green	0.044*	0.061**	0.068**
	(0.026)	(0.027)	(0.027)
Education	0.130	0.209**	0.230***
	(0.097)	(0.084)	(0.082)
City	2.877***	1.968***	2.004***
	(0.264)	(0.210)	(0.212)
Population	-0.242	0.362	0.533**
	(0.239)	(0.235)	(0.223)
Unit	0.069*	0.089**	
	(0.037)	(0.036)	
Environment		0.003	
		(0.008)	
_cons	-0.770	-4.656***	-5.042***
	(1.232)	(1.056)	(1.053)
N	270	300	300
R^2	0.686	0.668	0.660

6. Conclusions and Prospects

6.1 Research Summary

From the perspective of technology and environment, based on China's provincial panel data from 2011 to 2020, this paper explains the impact of on the from the aspects of direct effect and nonlinear effect. Using fixed effect model, dynamic panel GMM model, OLS model and threshold regression model, this essay investigates the direct impact, heterogeneous effect and nonlinear relationship between and at the national level and in three regions. The main conclusions are as follows:

(1) Based on the conditions of economic development and environmental protection, plays a significant role in promoting the Combined, helping to realize the beautiful vision of 2030.

(2) With regard to China's uneven regional economic development, the effects of on vary by region and exhibit the following features "east > west > middle".

(3) When itself is taken as the threshold variable, it has a significant multiple threshold effect on the Combined. When is greater than the cutoff point, which has a beneficial influence on the is greater.

6.2 Policy Implications

(1) The previous research shows that can promote the Combined. On the one hand, we should accelerate the application of clean energy and the encouragement of low-carbon or zero-carbon businesses' technological research and development to improve energy efficiency, transform production and life styles, and encourage Combined. On the other hand, the simultaneous prevention and control of pollution and carbon reduction, as well as the dual management of energy consumption intensity and total amount should be implemented by means of energy conservation and energy efficiency improvement.

(2) At the same time, this paper also finds that the on boosting presents the regional heterogeneity of "east > west > middle". Therefore, the eastern non-energy rich areas should guard against arrogance and impatience, steadily improve the level of Green, and promote the Combined. The country's coordinated efforts to reduce pollution and carbon emissions should be fully utilized by the energy-rich areas in the central and western regions, enthusiastically introduce talents and elites and green high and new technologies, and seize the dividends of development.

6.3 Future Outlook

While this research assesses and evaluates Green's impact mechanism on the and makes recommendations based on the current circumstances, there are still certain limitations: (1) In terms of research objects, this paper takes 30 provinces across the country as the research objects, further, we can try to sink the research level, incorporate the micro data of cities to carry out specific research, study the level of in key cities, and put forward more accurate development guidelines for according to the characteristics of different industries. (2) In terms of variable measurement, this study investigates Green's mechanism of action on the Combined. In the subsequent research, we can try to include other threshold variables such as resource misallocation, so as to more comprehensively reveal the mechanism "black box" of for Combined.

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