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Research on the Impact Mechanism of Green Technology Innovation on ESG performance

-- Regulatory effects based on environmental regulation

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Abstract: In the context of " Carbon peaking and carbon neutrality goals", the ESG concept of integrated environment, society and governance is an important standard for evaluating enterprises in promoting green and sustainable development of economy and fulfilling social responsibility. How to improve enterprise ESG performance is very important, and green technology innovation is one of the key ways to achieve enterprise ESG goals. Based on the panel data of A-share listed companies from 2009 to 2022, this paper uses the fixed-effect model for empirical testing. The research shows that green technology innovation has a significant role in promoting the ESG performance of enterprises; Environmental regulation plays a negative regulating role. The green technology innovation is divided into green product innovation and green process innovation, and it is found that green process innovation contributes to the improvement of green product innovation, so as to promote the ESG performance of enterprises. The impact of green technology innovation on ESG performance of enterprises is heterogeneous. For state-owned enterprises, enterprises in central and western regions and heavily polluting enterprises, improving green technology innovation can have a more positive impact on ESG performance of enterprises. In addition, after a series of endogeneity and robustness tests, the above conclusions are still valid. Businesses and governments should work together to promote green technology innovation to enhance ESG performance and promote green and sustainable economic and social development.

Keywords: Green technology innovation, Enterprise ESG performance, Environmental regulation, Green process innovation, Green product innovation.

1. Introduction

After 40 years of reform and opening up, China's rapid economic growth has also caused serious negative effects on ecological environment. (Jin Xin et al., 2022) In this grim context, China's proposed "carbon peak" and "carbon neutral"," Carbon peaking and carbon neutrality goals " policy has become the common goal of governments and international organizations. The report of the 20th National Congress of the Communist Party of China pointed out that high-quality development is a development in which green has become a common form, and promoting green and low-carbon economic and social development is a key link to achieve high-quality development. With the establishment and improvement of China's green low-carbon circular development economic system, green technology innovation has increasingly become an important driving force and necessary way for green development and high-quality development (Huang and Li, 2017).

In the macro environment of China's accelerating economic green transformation, the business philosophy at the micro enterprise level is being reshaped by the social responsibility requirements caused by green, low-carbon and sustainable development (Xie Hongjun and Lv Xue, 2022). The concept of environment, social and governance (ESG), proposed by the United Nations Principles for Responsible Investment (UNPRI), is currently an important standard for the international community to evaluate enterprises in promoting green and sustainable economic development and fulfilling social responsibilities. Among them, green technology innovation is one of the key ways to achieve enterprise ESG goals.

Research shows that green technology innovation can significantly improve the environmental performance and economic performance of enterprises, and has a positive impact on the competitiveness of enterprises (Wang Mingyue et al., 2021; Su Yuan et al., 2021). Although the importance of green technology innovation is widely recognized, companies still face significant challenges in the process of green transformation, including the high cost of technology research and development, uncertainty in market acceptance, and the imperfect policy and institutional environment. Although existing studies have explored the necessity and potential benefits of green technology innovation, as well as the many ways in which green technology innovation can affect firm performance, unfortunately, few literatures have directly linked green technology innovation with firm ESG performance.

So, can enterprises' green technology innovation behavior affect their ESG performance? The purpose of this paper is to study the relationship between green technology innovation and ESG performance, and the mechanism between the two. The innovation of this study is that it not only focuses on the overall impact of green technology innovation on ESG and the regulatory effect of environmental regulation, but further subdivides green technology innovation into two dimensions of green process innovation and green product innovation for discussion. This segmentation will help to reveal how different types of green innovation affect the environmental, social and governance performance of enterprises through mechanisms, so as to provide theoretical basis and practical guidance for enterprises to formulate more accurate and effective green technology innovation strategies. At the same

time, two core intermediary variables, product differentiation and market competitiveness, are added to explore the impact. The purpose of this study is to provide strategic guidance to enterprises to help them implement green technology innovation more effectively, improve their ESG performance, and promote the green and sustainable development of the economy and society.

2. Literature Review

2.1. Green Technology Innovation

Braun and Wield (1994) first proposed the concept of "green innovation technology", which covers the process technology and products that can improve the efficiency of resource use and reduce the environmental pollution load in the production process. Green technological innovation, also known as eco-innovation, environmental innovation, green innovation and sustainable development innovation, refers to a class of technological innovation that can promote resource efficiency and reduce environmental pollution (OECD 2010; Cai and Zhou, 2014).

The driving factors of green technology innovation have received widespread attention, and the existing studies have mainly analyzed them from the macro and micro perspectives (Zheng Yuanzhen et al., 2023). At the macro level, most studies are based on Porter's hypothesis to explore the impact path and mechanism of environmental regulation on green technology innovation (Popp, 2002; Xu Jia and Cui Jingbo, 2020). At the micro level, studies mostly focus on the internal management and governance structure of enterprises and stakeholders in the market, and discuss the promoting role of factors such as corporate governance mechanism and knowledge management in green technology innovation (Zheng Yuanzhen et al., 2023). Huang (2017) and Wang Fengzheng et al. (2018) believe that coordination ability and board governance can promote green technology innovation. From the perspective of resource-based theory, Yu Fei et al. (2019) deeply discussed how knowledge coupling affects the green innovation process of enterprises and revealed the internal logic and action path of this influencing mechanism. Research on the economic consequences of green technology innovation mainly focuses on its impact on enterprise performance (Wang Mingyue et al., 2021; Zhao Shukuan et al., 2022; Jia Chunxiang et al., 2023), in which Wang Mingyue et al. (2021) subdivided its impact on corporate economic performance and corporate environmental performance, and found the long-term negative impact of green technology innovation on corporate performance. In summary, green technology innovation and ESG covering environment, society and governance are bound to form a close link. Therefore, in this context, it becomes even more important to study how the promotion of green technology innovation affects the ESG performance of enterprises.

2.2. ESG Performance

The ESG concept was first proposed by the United Nations Environment Programme in 2004, emphasizing that enterprises should simultaneously focus on their environmental, social responsibility and governance performance while pursuing economic efficiency. Specifically, this means that enterprises should be committed to environmental protection, fulfilling social obligations, and improving corporate governance in the process of development (Sun Weizheng, 2020).

Domestic and foreign scholars have extensively discussed and analyzed ESG issues, and the research focus is generally focused on the relationship between ESG performance and corporate performance. However, the relevant research results did not reach a consensus, but presented two completely different test results (Li Jinglin et al., 2021). Aboud (2018) found that there is a positive correlation between ESG index and corporate value measured by Tobin Q, that is, companies with good ESG performance tend to have a higher value assessment in the market. Conversely, ESG-related poor performance will have a significant negative impact on corporate performance. Similarly, Yuan Yehu et al. (2021) believe that those enterprises with higher ESG scores generally show better overall performance. In terms of the mechanism of action, good ESG performance of enterprises can effectively reduce the financing constraints of enterprises, improve their operating efficiency, and reduce financial risks. These factors work together to significantly improve the market value of enterprises (Wang Linlin et al., 2022). However, neoclassical economic theory holds that firm ESG performance is irrelevant or negatively correlated with firm performance (Ruhaya et al, 2018; Duque-Grisales et al., 2021).

In recent years, the Chinese government has attached great importance to the concept of ESG, no longer confined to the study of the economic consequences of ESG behavior, and further explored the factors affecting the ESG performance of enterprises. According to the research of Sun Dong et al. (2019), if a company has strong solvency, profitability and reasonable capital structure, it can improve its ESG performance. Driven by the scientific and technological revolution and the industrial revolution, the development of urban digital economy and digital transformation are also one of the important factors to improve the ESG performance of enterprises (Wang Haijun et al., 2023; Hu Jie et al., 2023; Yang Yongjie et al., 2023; Bi Dayan et al., 2024), Wang Yinghuan and Guo Yongzhen (2023) further found the "inverted U-shaped" relationship between enterprise digital transformation and enterprise ESG performance on this basis to fill the theoretical gap. Wang Pei et al. (2021) found that green technology innovation played an intermediary role in the process of environmental protection tax affecting the ESG performance of enterprises, and enriched the influence path. Similarly, Yang Yongjie et al. (2023) added the mediating effect of green technology innovation to the study on digital transformation to improve ESG. Zheng Yuanzhen et al. (2023) studied the direct relationship between the two, believed that enterprise green technology innovation would promote enterprise ESG performance, and explored the heterogeneous relationship between utility model green technology innovation and innovation-type green technology innovation. On the basis of existing studies, this paper introduces the moderating effect and deeper heterogeneity analysis to further explore the possible complex relationship and mechanism between green technology innovation and ESG performance of enterprises, in an attempt to fill the gap of existing studies.

3. Hypothesis Proposal

3.1. Green Technology Innovation and ESG

Companies have huge environmental responsibilities. The core of sustainable development theory is to balance the relationship between economy, society and environment, which is one of the theoretical pillars of ESG (Huang

Shizhong, 2021). Green technology innovation can help enterprises achieve economic growth while reducing the negative impact on the environment and promoting the improvement of social well-being. This kind of innovation helps businesses and society achieve long-term sustainability goals.

Enterprises shoulder social responsibility. ESG is developed on the basis of corporate social responsibility (CSR). The development of the concept of corporate social responsibility provides a solid theoretical support for the wide dissemination and in-depth development of the concept of ESG. This shift has encouraged companies to pay more attention to environmental protection, social issues and governance structures, creating a positive social environment for the promotion of ESG. This new corporate attitude helps enterprises to take social benefits into account while pursuing economic benefits (Huang Shizhong, 2021). Green technology innovation is an important means for enterprises to achieve their social responsibility goals. By reducing environmental pollution and improving resource efficiency, enterprises can demonstrate their sense of social and environmental responsibility.

Enterprises need dynamic corporate governance to achieve sustainable development. Barney (1991) believes that the competitive advantage of enterprises comes from their unique resources and capabilities, which is the resource-based theory (RBV). Green technology innovation is an important resource for businesses that can lead to cost savings, new product development and market opportunities, and as companies change their resource base and capabilities, their internal and external environmental elements adjust accordingly. This alignment aims to create unique properties of resources, energy and materials that give firms a competitive advantage and enable strategic transformation to differentiate themselves in the market and improve their long-term performance (Claudia et al, 2014). To sum up, green technology innovation has a positive impact on ESG from the three paths of environment, society and corporate governance, forming a comprehensive promoting effect.

Based on the above theories, this paper proposes hypothesis 1:

H1: Enterprises' green technology innovation has a significant promoting effect on their ESG performance.

3.2. The Regulatory Role of Environmental Regulations

Environmental regulation is a legally binding environmental protection measure and standard formulated by the government in accordance with laws and regulations, which constitutes a mandatory normative pressure (Ma Zhisheng et al., 2024). Ren Yuejun and Zhang Kaihua (2016) found that the regulatory requirements imposed by the government have a significant impact on the environmental protection behavior norms of enterprises. According to the regulation cost theory, excessive regulation will aggravate the operating cost and pressure of enterprises, which may in turn lead to insufficient resource allocation of enterprises in other fields, thus limiting the autonomy and market competitiveness of enterprises. If environmental costs are too high, on the one hand, in order to minimize costs, many companies may take passive measures such as suspending some production to comply with regulatory requirements. This practice may lead to a reduction in the production scale of enterprises, which has a negative impact on the application and transformation of enterprises' green innovation achievements (Cui Guanghui et al., 2019). On the other hand, in order to comply with environmental regulations, enterprises need to invest a lot of money in equipment upgrading, technological transformation, etc., to reduce environmental pollution. This increases the operating cost of enterprises and reduces the enthusiasm of enterprises to carry out green technology innovation. Green technology innovation often requires a longer R&D cycle and a higher R&D investment. Under strict environmental regulations, enterprises face greater market risks and policy risks, which may lead to the weakening of enterprises' willingness to invest in green technology innovation. These chain reactions can pose major challenges to the overall operation and long-term development of the enterprise, harm the ESG performance of the enterprise, and may even threaten the survival of the enterprise.

In summary, hypothesis 2 is proposed:

H2: Environmental regulations negatively regulate the relationship between green technology innovation and firm ESG performance.

3.3. Intermediary Role of Enterprise Green Product Innovation

Generally, green technology innovation is divided into green process innovation and green product innovation (XIE, 2019). Green process innovation can significantly improve the utilization efficiency of resources and energy, while reducing the consumption of energy and other production resources in the process of production and waste recycling (LID, 2017). According to Wang Mingyue et al. (2021), green product innovation is mainly manifested in the use of non-toxic or biodegradable materials to adjust or optimize product production processes, with the goal of reducing environmental damage and enhancing resource and energy efficiency. Existing research emphasizes that green product innovation is one of the keys to achieving economic growth and environmental sustainability. In the practice of enterprises, there is a close interaction between green technology innovation and green product innovation. Green process innovation involves the systematic improvement of the entire operation and management process of the enterprise, with the aim of improving the efficiency of resource and energy utilization. This process also creates favorable conditions for the design and production of green products, thus providing a solid foundation for green product innovation. Through green process innovation, enterprises can effectively integrate environmental protection measures into product production, and then develop green products with market competitiveness. Green product innovation is a key link to turn green process innovation into a market advantage, which translates environmental improvement in the production process into market products that consumers can perceive and buy. This innovation not only helps companies meet the growing demand for environmental protection, but also establishes a green image in the market and enhances consumer brand loyalty. Finally, green product innovation helps enterprises to successfully launch new green products through its competitive advantages, and then stand out in the fierce market competition, improve the ESG performance of enterprises, achieve sustainable development, and contribute to economic growth.

Based on this, hypothesis 3 is proposed:

H3: Enterprise green process innovation improves

enterprise ESG performance through green product innovation.

To sum up, the research framework of this paper is shown in Figure 1:

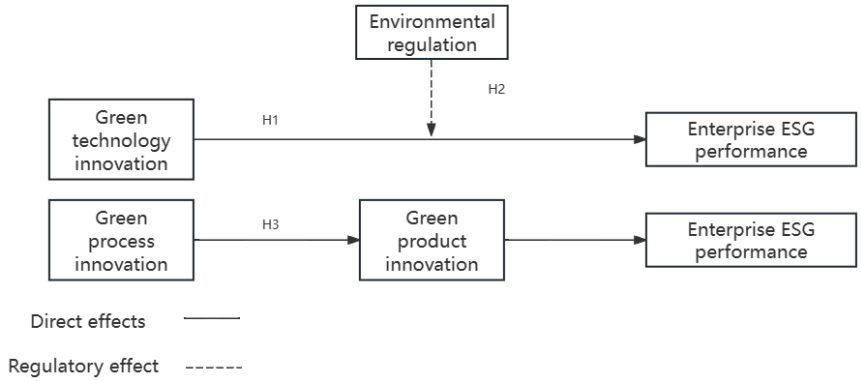


Figure 1. Theoretical research model

4. Research Design

4.1. Sample Selection and Data Source

All A-share listed companies from 2009 to 2022 were selected as the initial research objects. In order to ensure the reliability of variable data, the source data were screened as follows: (1) Listed companies with ST and *ST and those with abnormal or missing values were excluded; (2) Excluding companies in the financial industry during the study period; (3) In order to avoid the influence of extreme values, Winsor tail reduction is performed on all continuous variables at the level of 1% and 99%. Finally, the panel data of 4,097 annual observations from 4,914 enterprises were obtained. Among them, the ESG data of listed companies comes from the ESG total score of China's A-share listed companies disclosed by China Securities; Green product innovation and green process innovation came from the "Annual Social Responsibility Report" and "Annual Report", using content analysis, and other original data from the National Tai 'an database (CSMAR).

4.2. Variable Measurement

(1) Enterprise ESG performance (ESG). Referring to the research results of Wang Linlin et al. (2022), this study uses the ESG rating index of China Securities to evaluate the ESG performance of enterprises. Compared with other rating agencies, CSC's ESG evaluation system combines the international mainstream ESG evaluation model, and fully considers the characteristics of China's capital market and listed companies. The system is updated on a quarterly basis and covers all listed companies. It is known for its fast update speed and extensive coverage. The ESG rating of Sino Securities is divided into nine grades, which are C, CC, CCC, B, BB, BBB, A, AA and AAA, and its comprehensive score is used in this paper.

(2) Green Technology Innovation (GNI). Referring to the measurement method proposed by Xu Jia and Cui Jingbo (2021), the annual number of green patent applications of enterprises is used to measure the green technology innovation of enterprises, and the number of green patent applications is processed by adding one and then taking logarithm.

(3) Green Process Innovation (Proc), Green Product innovation (Prod). Referring to the method of Xie Xuemei et al. (2021), green process innovation is measured by 5 indicators; Green product innovation is measured using four indicators. If the enterprise has a written description of the relevant indicators in the social responsibility report, the score is 1; If the description contains quantitative information or is elaborated in detail, the score is 2; If there is no description, the score is 0; Finally, the score is added and the logarithm is taken after adding 1.

(4) Environmental Regulation (ENR). With reference to the method proposed by Liu Rongzeng et al. (2021), environmental regulation is measured from the intensity of environmental regulation, and the impact of environmental regulation is assessed by calculating the proportion of the completed investment in industrial pollution control to the total output value of the secondary industry.

(5) Control variables: (1) Enterprise Size. The natural logarithm of the total assets of an enterprise is used for measurement (Xu Jianzhong et al., 2017). (2) Asset-liability ratio (Lev). The ratio of total liabilities to total assets at the end of the year is expressed. (3) Return on equity (ROE). Net profit as a percentage of the average balance of owners' equity. (4) Inventory ratio (INV). Expressed as a proportion of net inventory to total assets. (5) Number of directors. The number of board members is measured by the natural logarithm. (6) The proportion of the largest shareholder (Top1). It is measured by the proportion of the number of shares held by the largest shareholder to the total number of shares.

The measurement methods of each variable are shown in Table 1.

Table 1. Variable definitions

Variable category	Variable name	symbol	measurement
The explanatory variable	green innovation	GNI	using the natural logarithm of the number of green patent applications added by one
	Green process innovation	Proc	added 1 to the score after the sum to take the natural logarithm
Explained variable	ESG	ESG	according to the Chinese Certificate ESG rating and graded assignment in the Wind database
The mediating variable	green product innovation	Prod	added 1 to the score after adding the sum and measured the natural logarithm
Adjusted variable	Environmental regulation	ENR	Industrial pollution control investment in the proportion of the secondary industry to measure environmental regulation
Control variable	Company Size	Size	The natural logarithm of total annual assets
	Asset-liability ratio	Lev	Total liabilities at year-end/total assets at year-end
	Return on equity	ROE	Net profit/average balance of owners' equity
	Inventory ratio	INV	Net inventories/total assets
	Number of directors	Board	The number of board members is the natural logarithm
	The proportion of the largest shareholder	Top1	Number of shares held by the largest shareholder/total number of shares

4.3. Model Construction

In order to study the empirical impact of green technology innovation on ESG performance of enterprises, this paper takes GNI as explained variable and ESG as explanatory variable. At the same time, the empirical impact of green process innovation on ESG performance of enterprises is studied. With Proc as the explained variable, ESG as the explanatory variable, Prod as the mediating variable, and ENR as the regulating variable, the following model is constructed on the basis of controlling other variables:

$$ESG_{i,t} = \alpha_0 + \alpha_1 GNI_{i,t} + \alpha_2 Size_{i,t} + \alpha_3 Lev_{i,t} + \alpha_4 ROE_{i,t} + \alpha_5 INV_{i,t} + \alpha_6 Board_{i,t} + \alpha_7 Top1_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t}$$

$$Prod_{i,t} = \alpha_0 + \alpha_1 Proc_{i,t} + \alpha_2 Size_{i,t} + \alpha_3 Lev_{i,t} + \alpha_4 ROE_{i,t} + \alpha_5 INV_{i,t} + \alpha_6 Board_{i,t} + \alpha_7 Top1_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t}$$

$$ESG_{i,t} = \alpha_0 + \alpha_1 Proc_{i,t} + \alpha_2 Size_{i,t} + \alpha_3 Lev_{i,t} + \alpha_4 ROE_{i,t} + \alpha_5 INV_{i,t} + \alpha_6 Board_{i,t} + \alpha_7 Top1_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t}$$

$$ESG_{i,t} = \alpha_0 + \alpha_1 Proc_{i,t} + \alpha_2 Proc_{i,t} + \alpha_3 Size_{i,t} + \alpha_4 Lev_{i,t} + \alpha_5 ROE_{i,t} + \alpha_6 INV_{i,t} + \alpha_7 Board_{i,t} + \alpha_8 Top1_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t}$$

$$ESG_{i,t} = \alpha_0 + \alpha_1 GNI_{i,t} + \alpha_2 ENR_{i,t} + \alpha_3 GNI_{i,t} \cdot ENR_{i,t} + \alpha_4 Lev_{i,t} + \alpha_5 ROE_{i,t} + \alpha_6 INV_{i,t} + \alpha_7 Board_{i,t} + \alpha_8 Top1_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t}$$

Where α_0 is the intercept, α_n is the correlation coefficient, μ_i is the individual fixed effect, γ_t is the time fixed effect, i is the sample individual, t is the year, and $\varepsilon_{i,t}$ is the random disturbance term.

5. Empirical Results and Analysis

5.1. Descriptive Analysis and Correlation Analysis

Table 2 reports descriptive statistics for the main variables. The median and mean of ESG performance of enterprises are very close, indicating that the overall ESG performance score of enterprises is at a low level, while the standard deviation is large, indicating that the concentration of ESG performance of enterprises is low, and the difference between different enterprises is large. The mean value of green technology innovation is 0.387, which indicates that the overall level of green technology innovation of enterprises is low. At the same time, the average value of green product innovation is greater than the average value of green process innovation, indicating that the investment proportion of green product innovation is larger at this stage. The median and standard deviation of environmental regulation intensity are 0.001, indicating that the intensity of environmental regulation is not high and the difference between the environmental regulation intensity faced by different enterprises is small. The remaining control variables were within the normal range.

Table 2. Descriptive statistical results

Variable	sample size	standard	deviation median	mean	minimum	maximum
ESG	40000	5.159	73.40	73.09	56	84.18
GNI	40000	0.801	0	0.387	0	3.761
Proc	7738	0.932	1.099	1.108	0	3.526
Prod	7737	0.941	2.079	1.966	0	4.025
ENR	40000	0.00100	0.00100	0.00200	0	0.00600
Size	39000	1.283	21.96	22.16	19.95	26.02
Lev	39000	0.206	0.410	0.418	0.0550	0.869
ROE	37000	0.125	0.0710	0.0630	-0.553	0.348
INV	39000	0.129	0.112	0.142	0	0.655
Board	39000	0.197	2.197	2.122	1.609	2.639
Top1	39000	14.82	32.03	34.24	9	72.88

Table 3 reports Pearson correlation analysis results for major variables. There was a significant positive correlation between green technology innovation and ESG performance (β=0.156, p<0.01), there was a significant positive correlation between green process innovation and ESG performance (β=0.140, p<0.01), there was a significant positive correlation between green product innovation and ESG performance (β=0.129, p<0.01), there was a significant negative correlation between environmental regulation and ESG performance (β=-0.035, p<0.01), therefore, the hypothesis of this study has been preliminarily verified; Significant correlations were also shown between other variables and the firm's ESG performance, suggesting that the variables chosen were appropriate.

Table 3. Results of correlation analysis of variables

	ESG	GNI	Proc	Prod	ENR	Size	Lev	ROE	INV	Board	Top1
ESG	1.000										
GNI	0.156***	1.000									
Proc	0.140***	0.163***	1.000								
Prod	0.129***	0.145***	0.591***	1.000							
ENR	-0.035***	-0.059***	-0.025**	-0.042***	1.000						
Size	0.194***	0.228***	0.198***	0.126***	-0.005	1.000					
Lev	-0.090***	0.095***	0.030***	0.045***	0.058***	0.503***	1.000				
ROE	0.228***	0.054***	0.021*	-0.005	0.012**	0.116***	-0.181***	1.000			
INV	0.049***	-0.063***	-0.118***	-0.113***	0.041***	0.105***	0.306***	0.022***	1.000		
Board	0.029***	0.047***	0.098***	0.064***	0.090***	0.254***	0.152***	0.049***	-0.014***	1.000	
Top1	0.106***	0.014***	0.072***	0.051***	0.051***	0.181***	0.048***	0.153***	0.047***	0.021***	1.000
Note: * p < 0.1, ** p < 0.05, *** p < 0.01 same below.											

5.2. Main Effect Test

The regression test results of hypothesis H1 in this paper are shown in the table. From column (2), it can be seen that the regression t value of green technology innovation (GNI) on ESG performance of enterprises is 8.317, and the regression coefficient is significantly positive at 1% level (β=0.352, P < 0.01). Green technology innovation significantly improves ESG performance of enterprises. The hypothesis H1 in this paper is verified. Enterprises to carry out green technology innovation can bring cost savings, new product development and market opportunities, in the long run, enterprises to form a sound environmental awareness and social responsibility awareness, comprehensive improvement of enterprise ESG performance.

Table 4. Regression results of green technology innovation and ESG performance of enterprises

	(1)	(2)
	ESG	ESG
GNI	0.410***	0.352***
	(9.696)	(8.317)
Size		1.218***
		(23.870)
Lev		-4.733***
		(-22.187)
ROE		1.955***
		(9.903)
INV		0.930***
		(2.750)
Board		-0.533***
		(-2.788)
Top1		0.019***
		(5.887)
_cons	73.478***	49.524***
	(726.754)	(44.947)
N	40079	37036
R2	0.0137	0.0487
adj. R2	-0.1240	-0.0873
F	34.971	82.921

5.3. Mediation Effect Test

In order to examine the possible mediating role of green product innovation in the relationship between green process innovation and ESG (environmental, social and governance) performance, this study referred to the approach of Wen Zhonglin and Ye Baojuan (2014) and adopted the hierarchical test method to analyze the direct and intermediary effects. Next, the relationship between green process innovation, green product innovation and ESG will be further discussed. Secondly, this study will examine the impact of green process innovation and green product innovation on ESG. If the regression results of green process innovation on green product innovation are significant, and the regression results of green process innovation and green product innovation on ESG are significant, it indicates that the intermediary effect of green product innovation exists. If the regression results of green process innovation on green product innovation are significant, and in the regression coefficients of green process innovation and green product innovation on ESG, only the regression coefficients of green product innovation and ESG are significant, and the regression coefficients of green process innovation are not significant, it indicates that green product innovation has played a complete intermediary effect.

The regression results of mediation effects are shown in Table x. The results showed that in column (1), green process innovation had a significant positive effect on ESG (β=0.342, P < 0.01). In column (2), green process innovation had a significant positive effect on green product innovation (β=0.550, P < 0.01); In column (3), green process innovation and green product innovation have a significant positive impact on ESG (β=0.230, P < 0.01), and the coefficient decreases significantly, indicating that green product innovation plays an intermediary role between green process innovation and ESG performance, and green product innovation is the key link to transform green process innovation into market advantage. To improve enterprise ESG performance, hypothesis H3 is verified.

In addition, Sobel-Goodman test provides three test results: sobel, Goodman-1 and Goodman-2. It can be seen that Z-statistic values of the three test results are significantly positive in Table 5. The Z-statistic values of both Direct effect and Indirect effect are significantly positive, and the proportion of intermediary effect of green product innovation is 32.60%. This paper again proves the results of the above mediation effect test, that is, green product innovation plays an intermediary role between green technology innovation and enterprise ESG performance.

Table 5. Testing the mediating role of green product innovation

	(1)	(2)	(3)
	ESG	Prod	ESG
Proc	0.342***	0.550***	0.230***
	(5.070)	(49.958)	(2.889)
Prod			0.202***
			(2.634)
Size	1.445***	-0.038	1.452***
	(9.428)	(-1.511)	(9.472)
Lev	-3.886***	0.136	-3.916***
	(-6.792)	(1.457)	(-6.846)
ROE	1.340***	-0.109	1.364***
	(2.668)	(-1.326)	(2.719)
INV	1.530*	-0.073	1.536*
	(1.769)	(-0.520)	(1.777)
Board	-1.080**	0.266***	-1.164***
	(-2.545)	(3.834)	(-2.733)
Top1	0.013	0.003**	0.012
	(1.507)	(2.489)	(1.462)
_cons	45.018***	1.605***	44.773***
	(13.174)	(2.877)	(13.096)
Sobel	0.111*** (z=2.630)		
Goodman1	0.111*** (z=2.629)		
Goodman2	0.111*** (z=2.631)		
Indirect effect	0.111*** (z=2.630)		
Direct effect	0.230*** (z=2.889)		
Total effect	0.341*** (z=5.054)		
Proportion of total effect that is mediated	0.3260		
N	7543	7542	7542
R^2	0.0573	0.2997	0.0584
adj. R^2	-0.1158	0.1711	-0.1147
F	21.503	151.457	20.792

5.4. Adjustment Effect Test

On the basis of main regression, environmental regulation and its interaction with green technology innovation are introduced respectively to test their significance. In column 2, the interaction terms of green technology innovation and environmental regulation have a significant negative regulatory effect on the ESG performance of enterprises (β=-50.588, p<0.05), which indicates that environmental regulation has a negative moderating effect between green technology innovation and ESG performance, that is, assuming H2 is verified, under strict environmental regulation, enterprises will face greater market risks and policy risks, which may lead to the weakening of enterprises' investment intention in green technology innovation and harm the ESG performance of enterprises.

Table 6. Test of regulatory effects of environmental regulations

	(1)	(2)
	ESG	ESG
GNI	0.355***	0.349***
	(8.344)	(8.186)
GNI×ENR		-50.588**
		(-2.100)
ENR	71.032***	67.618***
	(2.878)	(2.734)
Size	1.210***	1.208***
	(23.634)	(23.585)
Lev	-4.730***	-4.726***
	(-22.030)	(-22.009)
ROE	1.952***	1.949***
	(9.862)	(9.843)
INV	1.003***	1.002***
	(2.956)	(2.954)
Board	-0.483**	-0.480**
	(-2.508)	(-2.491)
Top1	0.019***	0.019***
	(5.582)	(5.606)
_cons	49.462***	49.498***
	(44.694)	(44.724)
N	36592	36592
R^2	0.0487	0.0489
adj. R^2	-0.0875	-0.0874
F	78.074	74.734

6. Robustness Test

6.1. Variable Substitution Method

With reference to the method of Zheng Yuanzhen et al. (2023), the regression analysis was re-performed using Bloomberg ESG rating System (Bloomberg|ESG) as a substitute variable for ESG performance. It can be seen from the results that the impact of green technology innovation (GNI) on ESG performance of enterprises is significantly positive (β=0.531, P < 0.01), which is basically consistent with the original benchmark regression results, confirming the reliability of the conclusions of this study and the model.

Table 7. Replaces the test results for explained variables

	(1)	(2)
	BloombergESG	BloombergESG
GNI	0.594***	0.531***
	(8.188)	(7.313)
Size		1.290***
		(12.472)
Lev		-3.533***
		(-7.732)
ROE		2.686***
		(6.640)
INV		2.102***
		(2.904)
Board		0.245
		(0.662)
Top1		-0.001
		(-0.183)
_cons	17.998***	-10.049***
	(107.011)	(-4.369)
N	13379	12847
R^2	0.7186	0.7283
adj. R^2	0.6838	0.6947
F	2171.735	1532.119

6.2. Endogenous Problems

This paper focuses on the relationship between green technology innovation and ESG performance. In the process of research, it is found that there may be a two-way causal problem between the two, that is, enterprises with good ESG performance tend to have more complete internal governance structure and long-term development strategy, which may encourage enterprises to invest more in green technology innovation to achieve long-term sustainable development. In order to verify the existence of this bi-directional causality problem, the delayed one-phase regression method is adopted in this paper. The ESG performance of the dependent variable is delayed by one stage, and then regression analysis is performed with green technology innovation. According to the results in Table 8, the regression results of the dependent variable after one-stage lag processing are still positive and significant, which indicates that the research results are robust.

Table 8. Test results considering delay effect

	(1)	(2)
	ESG	L.ESG
lnGI	0.352***	0.253***
	(8.317)	(5.742)
Size	1.218***	1.295***
	(23.870)	(23.289)
Lev	-4.733***	-4.221***
	(-22.187)	(-18.319)
ROE	1.955***	0.276
	(9.903)	(1.321)
INV	0.930***	0.758**
	(2.750)	(2.095)
Board	-0.533***	-0.338*
	(-2.788)	(-1.676)
Top1	0.019***	0.038***
	(5.887)	(10.805)
_cons	49.524***	46.701***
	(44.947)	(38.788)
N	37036	33859
R^2	0.0487	0.0415
adj. R^2	-0.0873	-0.1004
F	82.921	67.222

7. Heterogeneity Analysis

7.1. Influence of Enterprise Ownership Type

The ownership characteristics of enterprises often have a differentiated impact on their R&D investment and technological innovation results. State-owned enterprises have more abundant material, capital and human resources, which makes them have a stronger ability to practice ESG. At the same time, as the main implemutors of key national strategies and policies, soes play a key role in responding to government initiatives and assuming national and social responsibilities. In the context of "dual carbon", state-owned enterprises have the responsibility to promote green technology innovation and assume broader social responsibilities. Therefore, green technology innovation has a more obvious promoting effect on the ESG performance of state-owned enterprises (Hu Jie et al., 2023). Therefore, in this study, based on the benchmark model, the sample is divided into state-owned enterprises and non-state-owned enterprises according to the ownership nature of enterprises, and a grouping regression analysis is conducted to further explore whether green technology innovation will have different impacts on the ESG performance of these two types of

enterprises. Columns (1) and (2) in Table x show the results of this analysis. The results showed that compared with non-state-owned enterprises (β=0.256, p<0.01), green technology innovation has a stronger positive impact on ESG performance of state-owned enterprises (β=0.302, p<0.01), this difference is significant.

Table 9. Influence of enterprise ownership type

	State-owned enterprise	Non-state-owned enterprise
	ESG	ESG
lnGI	0.302***	0.256***
	(4.687)	(4.484)
Size	1.341***	1.317***
	(16.110)	(19.115)
Lev	-3.396***	-4.687***
	(-9.503)	(-16.644)
ROE	0.880***	1.906***
	(2.715)	(7.363)
INV	-0.395	1.128**
	(-0.732)	(2.482)
Board	-0.454	-0.591**
	(-1.529)	(-2.273)
Top1	-0.015***	0.026***
	(-2.801)	(5.523)
_cons	47.080***	48.117***
	(25.810)	(32.649)
N	13419	22886
R^2	0.0552	0.0626
adj. R^2	-0.0561	-0.1065
F	35.089	64.746

7.2. Impact of Regional Differences

In this paper, referring to the method of Shen Xiaobo et al. (2021), the sample is divided into three regions according to the geographical location of the enterprise, namely the eastern, central and western regions, and the grouped regression is carried out respectively. Compared with the central and western regions, the eastern region is more advanced in economic and technological development, both of which are better than the central and western regions, so its ESG performance has reached a relatively high level, making the marginal effect of green technology innovation relatively small. At the same time, the central and western regions have more industries with high pollution and high energy consumption, and these industries have improved their ESG performance more significantly after implementing green technology innovation. The results showed that compared with the eastern (β=0.305, p<0.01) In terms of green technology innovation in the central region (β=0.452, p<0.01) and western region (β=0.426, p<0.01) has a more significant promoting effect on enterprise ESG performance. Therefore, the promotion effect of green technology innovation on enterprise ESG performance is more obvious in the central and western regions.

Table 10. Effects of regional differences

	East	Central	West
	ESG	ESG	ESG
lnGI	0.305***	0.452***	0.426***
	(6.111)	(3.672)	(4.047)
Size	1.199***	1.350***	1.324***
	(19.088)	(10.133)	(10.351)
Lev	-4.768***	-4.955***	-4.068***
	(-18.413)	(-9.014)	(-7.481)
ROE	1.896***	2.194***	1.458***
	(7.886)	(4.306)	(3.004)
INV	1.158***	0.983	0.021
	(2.915)	(1.004)	(0.023)
Board	-0.652***	-1.612***	0.876*
	(-2.802)	(-3.155)	(1.922)
Top1	0.029***	0.005	0.003
	(7.088)	(0.555)	(0.417)
_cons	49.836***	49.474***	44.378***
	(36.645)	(16.761)	(16.322)
N	26089	4974	5963
R^2	0.0485	0.0607	0.0528
adj. R^2	-0.0957	-0.0616	-0.0780
F	57.719	14.223	14.591

7.3. Impact of Industry Type

In order to encourage more funds to flow to enterprises committed to saving resources and protecting the environment, the country has launched a series of green credit and green finance policy measures. The implementation of these policies has seen positive effects, which are reflected in the significant increase in financing costs faced by enterprises in heavily polluting industries (Su Dongwei and Lian Lili, 2018). So, will heavy polluting enterprises strengthen green technology innovation to improve their ESG performance? Based on the practice of Wang Ypan et al. (2021), this paper divides the samples into heavy polluting enterprises and other enterprises for testing. The results of Table x show that green technology innovation has a more significant promoting effect on the ESG performance of heavy polluting enterprises. Heavy polluting enterprises have a more significant impact on the environment due to the characteristics of their production activities, so their environmental, social and governance (ESG) performance is significantly different from that of other enterprises. Through the classification test, we can more clearly observe the different impact of green technology innovation on the ESG performance of these two types of enterprises.

Table 11. Impact of industry type

	Other enterprises	Heavy polluting enterprise
	ESG	ESG
lnGI	0.270***	0.373***
	(3.143)	(7.688)
Size	1.235***	1.285***
	(10.371)	(21.781)
Lev	-5.059***	-4.733***
	(-10.567)	(-19.340)
ROE	0.328	2.486***
	(0.772)	(11.022)
INV	1.279	0.752**
	(1.190)	(2.069)
Board	-0.889**	-0.565***
	(-2.114)	(-2.615)
Top1	0.011	0.022***
	(1.546)	(5.584)
_cons	50.663***	47.899***
	(19.645)	(37.613)
N	8474	28562
R^2	0.0540	0.0545
adj. R^2	-0.0871	-0.0890
F	21.045	71.448

8. Research Conclusions and Implications

8.1. Research Conclusions

Based on the panel data of A-share listed companies from 2009 to 2022, this paper adopts the fixed-effect model for empirical testing, takes green technology innovation as explanatory variable, comprehensively considers the effects of green process innovation, green product innovation and environmental regulation on ESG performance of enterprises, and constructs the impact model of green technology innovation on ESG performance of enterprises, and draws the following conclusions: (1) Enterprises' green technology innovation has a significant promoting effect on their ESG performance. (2) Environmental regulations negatively regulate the relationship between green technology innovation and firm ESG performance. (3) Enterprise green process innovation promotes enterprise ESG performance through green product innovation.

8.2. Revelation

On the one hand, companies should recognize that by investing more in green process innovation and green product innovation, they can effectively improve their ESG performance. This will not only help companies stand out in the increasingly fierce market competition, but also meet the needs of consumers and investors for sustainable development. Companies can advance this process by setting up dedicated green technology innovation teams, collaborating with research institutions, and investing in new technologies. State-owned enterprises, enterprises in central and western regions and heavily polluting enterprises should pay more attention to green technology innovation. These enterprises play an important role in the economy, but are often a major source of environmental pollution. By implementing green technology innovations, these companies can not only improve their own ESG performance, but also have a positive impact on the sustainability of the entire industry. In addition, companies need to pay close attention to changes in environmental regulations to ensure that their green technology innovation activities comply with the latest policy requirements. At the same time, enterprises should actively communicate with the government to feedback the negative impact of excessive environmental regulations on green technology innovation and seek reasonable solutions.

On the other hand, the government should further improve environmental regulations. It should not only put enough pressure on enterprises to increase their efforts in green technology innovation, but also provide corresponding policy support to help enterprises overcome difficulties and challenges in the innovation process. This can be achieved by setting up a green technology innovation fund, providing tax incentives, and establishing a green technology innovation platform. The government can give more policy support to state-owned enterprises, enterprises in central and western regions and heavy polluting enterprises, such as providing subsidies for green technology innovation and giving priority to green project loans to these enterprises. This will help these enterprises better meet the challenges of green technology innovation, while promoting the coordinated development of the regional economy and the environment. In addition, the government can guide funds to green technology innovation through policy means such as green credit and green finance. Especially for heavy polluting enterprises, the government can provide more green loans and investment opportunities to encourage them to transform into green and sustainable enterprises. The government should also increase its support for the research and development and application of green technology innovation, such as setting up special funds, providing financial support, and promoting the transformation of green technology innovation achievements. This will help promote the rapid development of green technology and promote the green and sustainable development of the economy and society.

This paper provides guidance for enterprises to improve ESG through green technology innovation, and also provides reference for the government to formulate relevant environmental regulations and industrial policies. Both enterprises and governments should attach importance to green technology innovation and jointly promote the green and sustainable development of the economy and society. This not only helps to improve the market competitiveness of enterprises, but also promotes the realization of environmental protection and social responsibility.

8.3. Deficiencies and Prospects

The measurement of green technology innovation relies too much on patent data, which may not fully reflect the overall situation of green technology innovation, and needs to be combined with other indicators for comprehensive evaluation. This paper only examines the mediating role of green product innovation, but in reality, there are still other important factors that affect the relationship between green technology innovation and ESG performance of enterprises. Whether there are other mediating paths still deserves constant attention. In the future, we can further enrich the mechanism test and expand the research perspective.

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