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Jingya Wang and Xilong Yao *

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The Signaling Mechanism of Corporate Environmental Expenditure and Green Innovation

Jingya Wang [1], Xilong Yao [2,*]

School of Economics and Management ,Taiyuan University of Technology, Taiyuan, 030024, China; wangjy4747@163.com
* Correspondence: xlyao2025@163.com
† Current address: School of Economics and Management ,Taiyuan University of Technology, Taiyuan 030024, China
‡ These authors contributed equally to this work.

Abstract: Environmental protection expenditure of enterprises is an important investment to realize green innovation. Although a large number of literatures have evaluated the factors promoting green innovation, few literatures have studied the impact of environmental protection expenditure of enterprises on green innovation, and signal transmission is an important way and mechanism. This paper selects the data of China's Shanghai and Shenzhen A-share listed companies from 2012 to 2023, obtains the data of enterprise environmental protection investment through manual collection and keyword screening method, and analyzes the micro impact of enterprise environmental protection investment on green innovation output by using two-way fixed corresponding method. The empirical results show that the environmental protection expenditure of enterprises will significantly promote green innovation. At the same time, the green innovation effect of enterprise environmental protection expenditure is also different due to enterprise scale, financing constraints and life cycle. At the same time, this paper verifies the signal transmission mechanism of enterprises' environmental protection expenditure, that is, enterprises' investment in environmental protection will release positive signals to the outside, so as to strive for more social resources. Further empirical analysis verifies the promotion effect of enterprise environmental protection expenditure on performance. This paper believes that enterprises should play a positive role in environmental protection investment, and government departments should increase support for enterprises.

Keywords: environmental protection expenditure; green innovation; signal transmission mechanism; environmental performance

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1. Introduction

With the development of China's economy from high-speed growth to high-quality development, sustainable economic growth and green development have become urgent problems to be solved. The 20th CPC National Congress pointed out that we should unswervingly follow the path of ecological priority, green and low-carbon development, and strive to promote the comprehensive green transformation of economic and social development, which requires both development and environment. However, China is currently facing serious environmental pollution problems, and green development is facing severe challenges. Green innovation has increasingly become an important factor in promoting the healthy development of China's economy. According to the 2023 global carbon emissions report released by the International Energy Agency (IEA), China's carbon dioxide emissions account for about 34% of the global carbon dioxide emissions, and continue to rank first in the world. China's carbon emissions have been 15% higher than the total emissions of developed economies since 2020. As a source of vitality driven by green innovation, enterprises are always the focus and focus of attention from all walks of life. Enterprises are not only the main body of social and economic activities, but also the main body of innovation activities. They have the ability to transform technological advantages into commodity advantages and return innovative achievements through the market.

In this context, energy conservation and environmental protection, emission reduction and green development have become the main theme of structural adjustment. Green innovation is not only conducive to promoting enterprises' rational use of resources and reducing pollution, but also can promote the industry to accelerate the transformation of development mode. In fact, green innovation plays an indispensable role in maintaining the balance between economic growth and environmental protection. Based on the characteristics of high innovation cost and long cycle, green innovation needs capital investment. In addition to the support of government policies, the environmental protection expenditure of enterprises directly affects the funds needed for the development of enterprises, so as to promote the development of green innovation.

At present, a large number of literatures have discussed the influencing factors and driving forces of green innovation [1–3].He [4] and others have determined that external factors such as social media's attitude towards pollution, economic policy uncertainty [5], external resources [6], and environmental regulation [7] are the main driving forces of green innovation [8]. The policy of using China's total amount control also believes that external factors drive green innovation of enterprises. Bossle [1] and others found that internal factors such as environmental awareness and environmental ability of senior executives help promote green innovation.

Because innovation has the characteristics of long cycle and high risk, government policies and subsidies have become one of the most common driving factors. With the development of government policies, there have been studies on the relationship between policy subsidies and green innovation [9,10]. Government subsidies have provided sufficient funds for enterprises and brought many changes, such as Chinese government subsidies to promote energy transformation and affect the performance of initial public offerings (IPOs) of start-ups [11]. However, there is a certain threshold for government subsidies. Once the subsidies expire, there will be a subsidy impact, and enterprises will adopt green drift business behaviors and strategies [12]. Some studies believe that the environmental protection expenditure of enterprises is to fulfill the environmental responsibility. The environmental protection expenditure will reduce the profitability of enterprises and reap a lower return on assets ROA. These reductions are regulated by the R&D investment [13]. Other studies take chemical enterprises as samples and believe that enterprises with environmental expenditure have better production efficiency and capacity [14]. Li [15] believed that enterprises' environmental capital expenditure would send a signal, which was favored by long-term institutional investors. In general, the existing literature on the research results of enterprise environmental protection expenditure is inconsistent, and the impact mechanism and boundary conditions on green innovation are relatively limited.

The new institutionalism theory points out that the survival and development of enterprises are highly dependent on the legitimacy of the external institutional environment. Increasingly stringent environmental regulations, industry standards and environmental demands of stakeholders force enterprises to fulfill environmental responsibilities through environmental protection expenditure, so as to avoid regulatory risks and obtain green legitimacy. However, this passive compliance logic is difficult to explain why some enterprises take the initiative to increase investment in environmental protection and use it to achieve green innovation breakthroughs. At this time, the signal theory provides a new perspective for analyzing the deep motivation of enterprises' environmental protection expenditure: environmental protection expenditure is not only a compliance response under the pressure of the system, but also a strategic signal of enterprises' green commitment and innovation ability to the government, investors and other external entities, so as to leverage scarce resources such as policy support and financing facilities, and form a virtuous cycle of "signal resource innovation". The intersection of the two theories shows that environmental protection expenditure is not only the product of passive institutional constraints, but also the tool of active strategic game, and its signal transmission efficiency is jointly regulated by institutional environment and enterprise capability.

By integrating new institutionalism and signaling theory, this study attempts to break through the traditional analytical framework that attributes environmental protection expenditure solely to institutional compliance or resource constraints, and reveal its complex mechanism as a carrier of dual

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attributes of institution strategy. This study uses the sample data of China's Shanghai and Shenzhen A-share listed companies from 2012 to 2023 to empirically test the impact of corporate environmental expenditure on green innovation. This study divides green innovation into two categories according to different behavioral motivations of enterprises: Strategic green innovation, which tries to win through the number of innovations; Substantive green innovation, promote real technological progress and gain market competitiveness.

Lerner [16]argues that government grants signal external stakeholders, attracting venture capital—a mechanism validated theoretically [17] and empirically [18]. Building on this, we investigate whether a similar signaling mechanism exists between corporate environmental expenditure and green innovation. Further, we examine the moderating role of environmental regulations to determine whether government policies shape the boundary conditions of this relationship.

Given China's goals of high-quality and sustainable development, this research is timely. Its findings can optimize the role of corporate environmental expenditure in promoting green innovation, contributing to global efforts against environmental pollution and climate change. The marginal contributions are threefold. First, while existing literature on corporate green innovation focuses on macro-level government policies (e.g., subsidies, pilot programs), this study examines the micro-level question of whether corporate environmental expenditure inherently possesses "green attributes" and enhances green innovation capabilities, linking environmental goals to value creation. Unlike prior studies categorizing green innovation by motivation and outcome [19], we delve into innovation motives, distinguishing substantive from strategic green innovation. Second, grounded in signaling theory, we empirically validate the mechanism through which environmental expenditure drives green innovation. By signaling commitment, environmental expenditure mobilizes external investments, fostering innovation. This micro-level analysis elucidates the transmission channels, demystifying the "black box" between environmental expenditure and green innovation. Third, the findings provide critical policy insights for promoting green innovation and sustainable development, informing regulatory and environmental infrastructure design.

The remainder of this paper is structured as follows: Section 2 presents the theoretical analysis and hypotheses; Section 3 details the empirical design; Section 4 discusses results; and Section 5 concludes with policy implications.

2. Theoretical Analysis and Research Hypotheses

2.1. Theoretical Analysis

According to institutional theory, compared with other organizations, enterprises that abide by external rules are more likely to survive and further develop. The new institutionalism theory points out that the essence of environmental protection expenditure decision is a dynamic game between institutional pressure and enterprise strategic response. When the environmental regulations become stricter and form a mandatory isomorphic pressure, enterprises' passive investment in environmental protection is often limited to terminal governance [20]; When the evolution of industry green standards forms imitative isomorphism, the proactive environmental investment of leading enterprises tends to process innovation. This interaction between institutional environment and corporate strategy shapes the heterogeneity of the impact of environmental protection expenditure on green innovation. Specifically, according to the new system theory, on the one hand, when enterprises are faced with the situation of strong government supervision and insufficient incentives, enterprises tend to promote strategic green innovation by rapidly increasing environmental protection expenditure. On the other hand, when enterprises carry out environmental protection expenditure and actively respond to government policies, they can send positive signals to the outside world and alleviate the problems that may be faced with high risks, which is conducive to promoting substantive green innovation activities and improving the performance of substantive green innovation.

Based on Spence's signaling theory, enterprises' environmental protection expenditure can be seen as a strong signal to the market that they are willing to bear environmental responsibility. In

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the market environment of asymmetric information, enterprises that actively disclose environmental protection investment can effectively distinguish themselves from competitors with low environmental protection investment and form differentiated reputation capital. This signaling mechanism forms dual incentives through the capital market premium effect [21] and consumer preference guidance [22]. On the one hand, it attracts investors with ESG preferences to reduce financing costs. On the other hand, it improves the market premium space of green products. This value reconstruction process provides the necessary financial guarantee and market verification channel for enterprises' green innovation, and drives R&D resources to tilt to the field of environmental protection technology. In the case of this study, it is difficult for enterprises to obtain government subsidies because it takes a long time for them to carry out green innovation activities, that is, green innovation has high uncertainty and risk, and even has the possibility of failure. As the main participants and promoters of green innovation, enterprises with resource allocation are the main body of strategic decision-making. They can master the direction of resource allocation and green innovation activities of enterprises, and promote the transformation of enterprise innovation achievements.

The results of existing literature on environmental protection expenditure of enterprises are mixed, on the one hand, on the other hand. By integrating signaling theory and institutional theory, this study systematically reveals the dual mechanism of the impact of environmental protection expenditure on green innovation. At the theoretical construction level, the research innovatively combines the information asymmetry cracking mechanism of signaling theory with the legitimacy acquisition logic of institutional theory. Most of the existing literatures used qualitative research methods, such as case study method, to explore the environmental protection expenditure of enterprises. This study empirically tests the impact of environmental protection expenditure on green innovation by using the data of Chinese listed companies. Based on the signal transmission theory, this paper tests the signal effectiveness of enterprise environmental protection expenditure to external investors. This cross level theoretical integration not only expands the research paradigm of sustainable innovation, but also provides an analytical framework with explanatory and predictive power.

2.2. Research Hypotheses

2.2.1. Impact of Corporate Environmental Expenditure on Green Innovation

Green innovation refers to the behavior of enterprises to improve ecological efficiency by taking some measures, including but not limited to technology improvement, process, management mode, etc., to reduce energy consumption, resource waste, and pollutant emissions [2]. Compared with traditional innovation activities, the most obvious feature of green innovation is that it produces more positive environmental externalities. At present, the scope of green innovation activities and the resources consumed are limited, and the scale is still relatively small [23]. Compared with other innovative behaviors, green innovation requires more capital investment. Enterprises' environmental protection expenditure and investment can effectively become the driving force of enterprises' green innovation. The environmental protection expenditure of an enterprise is considered to be the sum of the active or passive resources invested by the enterprise in order to travel for social responsibility and reduce the negative environmental impact brought by itself in the whole production and operation activities. Environmental protection expenditure is a kind of corporate behavior used by enterprises for R&D activities to prevent technology spillovers from leading to market failure. As an important tool for enterprises to realize the rational allocation of resources and the optimization and upgrading of industrial structure, environmental protection expenditure can help enterprises alleviate the crisis through the most direct capital investment, guide and encourage enterprises to invest in innovation activities, and ultimately achieve the purpose of improving innovation performance. When facing the pressure from the government, enterprises tend to carry out corresponding behavior to pursue the speed and quantity of green innovation to meet the policy demand, so as to improve the strategic innovation behavior. Based on this, this study proposes the following assumptions:

H1a. *The environmental protection expenditure of enterprises helps to promote strategic green innovation behavior.*

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For enterprises, the implementation of substantive green innovation often requires a lot of capital investment, accompanied by uncertainty and high-risk characteristics [24], so enterprises lack the motivation to obtain external investment and have a single source of capital. Environmental protection expenditure is not a simple cost consumption, but the internal driving force of green innovation through the reconstruction of internal elements and resources of enterprises. The redistribution of resources caused by environmental protection investment forces enterprises to re evaluate the choice of technological route. For example, the high expenditure on pollution control may prompt the R&D department to give priority to the development of source emission reduction technology to reduce the long-term treatment cost. This cost internalization mechanism converts environmental constraints into the priority setting of technological breakthroughs. The continuous investment in environmental protection will change the innovation evaluation criteria of enterprises, and promote the R&D decision-making from the single economic return orientation to the comprehensive consideration of the internalization of environmental benefits. The reconstruction of this value orientation will guide the innovation resources to gather in the technology field with substantial emission reduction potential, forming a positive match between the innovation direction and the environmental objectives. Based on this, this study proposes the following assumptions:

H1b. *The environmental protection expenditure of enterprises helps to promote substantive green innovation.*

2.2.2. Signal Transmission Mechanism of Enterprise Environmental Protection Expenditure

In the case of asymmetric information in the market, the environmental protection expenditure of enterprises, as an observable and committed investment, can convey the determination and ability of enterprise environmental governance and private information of sustainable development potential to external investors. Due to the specificity and irreversibility of environmental protection expenditure of enterprises, its scale and structure are the signals that distinguish environmental strategies. That is, enterprises with lower quality are difficult to make sustainable investment, resulting in sunk costs, while enterprises with higher quality can implement long-term environmental protection investment. On the one hand, environmental protection expenditure shows the ability of enterprises to actively respond to the environment, reducing the risk gap caused by environmental violations in the future. On the other hand, the technology investment and accumulation created by environmental protection expenditure have brought enterprises a first mover advantage in the market and enhanced investors' expectation of innovation premium, which is conducive to optimizing the rational allocation of resources.

The mechanism of signal transmission is not only to promote the favor of external investors, but also to reduce the uncertainty of enterprises and other technology partners, such as universities and research institutions. Signal transmission leads to the agglomeration of resources and the convergence of technological advantages, which has always promoted the improvement of enterprises' green innovation ability. Under this mechanism, venture capital tends to favor enterprises with high transparency of environmental protection expenditure and deep technology embeddedness, because it can observe the strong correlation between environmental protection investment and green patent output, thus forming a positive feedback loop of "environmental protection signal innovation expectation valuation premium". This selective incentive of the capital market essentially constructs a feedback channel of external resources for green innovation driven by environmental protection expenditure (as shown in Figure 1 below).

Based on this, this study proposes the following assumptions:

H2a. *The environmental protection expenditure of enterprises helps to promote strategic green innovation behavior.*

H2b. *The environmental protection expenditure of enterprises has a signal transmission mechanism, which helps to promote substantive green innovation behavior.*

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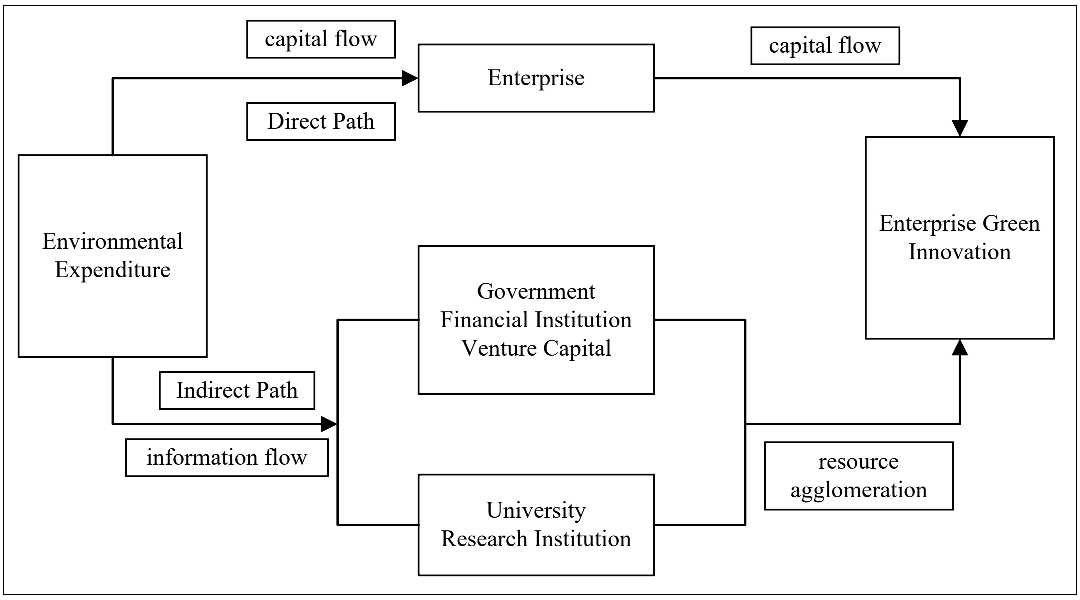

Figure 1. Framework of Environmental Expenditure's Signaling Mechanism.

3. Research Design

3.1. Sample Selection

This study selects the data of China's Shanghai and Shenzhen A-share listed companies from 2012 to 2023 to test the impact of corporate environmental protection expenditure on strategic green innovation and substantive green innovation. The main reason for selecting listed companies as the research sample is that the data is more available. Compared with non listed companies, the data of listed companies can be obtained from financial statements, annual reports and other information. The sample time began in 2012. The main reasons are as follows: (1) in 2012, the CSRC strengthened the supervision of information disclosure and revised the annual report standards of listed companies, which significantly improved the data quality; (2) 2023 is the latest deadline for currently available data. In order to ensure the timeliness of research results and fully reflect the latest developments in the capital market.

On this basis, this study processed the original data to reduce the errors and omissions of data and the lack of variables as much as possible: (1) Eliminate the financial, ST, ST* PT listed companies; (2) Eliminate listed companies with missing key variables; (3) For continuous variables, a 1% tailing treatment is carried out. Finally, 29520 research samples were obtained. Table 1 shows the descriptive statistics of the samples.

Table 1. Descriptive Statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
GIapply_strat	29520	0.627	0.984	0	6.317
GIapply_sub	29520	0.632	1.035	0	6.887
env	29520	0.054	0.078	0	0.239
size	29520	22.292	1.334	14.942	28.615
lev	29520	0.429	0.209	0.008	4.026
ED	29520	-13.875	0.929	-19.867	0
CD	29520	2.733	4.935	-19.918	289.885
SOE	29520	0.348	0.476	0	1
Dual	29520	0.283	0.450	0	1
IndepRatio	29520	0.376	0.055	0.143	0.800
BSize	29520	2.120	0.199	1.386	2.890
Top1	29520	33.798	14.895	0.290	89.990

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3.2. Variable Measurement

(1) Explained variables: Strategic Green Innovation (GIapply_strat) and substantive Green Innovation (GIapply_sub). According to Fleming and Sorenson [25], the number of patents of enterprises is an important indicator of innovation. At the same time, combined with the practice of boons et al. [2,26], this study uses the number of utility model and design patent applications in green patents to measure strategic green innovation, and uses the number of invention patent applications in green patents to measure substantive Green Innovation. According to the stock code of the selected sample of listed companies, combined with the China Intellectual Property Office and the IPC classification number of green patents, the relevant patent applications and authorized numbers of the sample companies are screened and sorted out, and the corresponding number of green invention patent applications and green utility models and designs are obtained. Finally, the number of applications is added by 1 to take the logarithm.

(2) Explanatory variable: environmental protection expenditure (env). Referring to the measurement method of Zhang [27], based on the details of "projects under construction" in the annual reports of listed companies, this study manually screened, collected and sorted out environmental protection projects and the corresponding amount. Among them, the projects related to environmental protection include "desulfurization project", "out of stock project", "sewage treatment", "environmental transformation", "pollution control", "purchase of environmental protection production line" and other forms. Finally, take the natural logarithm of the obtained project amount and divide it by 100 as the proxy variable of environmental protection expenditure.

(3) Control variables. This study mainly selects the variables that may affect the green innovation of enterprises from the enterprise level. The specific control variables are as follows. Enterprise financial leverage (lev) is the total liabilities divided by total assets at the end of the current period. Enterprise size is the total assets at the end of the current period. Employee intensity (ED) is the number of employees divided by operating revenue. Capital intensity (CD) is total assets divided by operating income. The nature of ownership (SOE) is 1 for state-owned enterprises and 0 for non-state-owned enterprises. Dual is 1 if the chairman and general manager are the same person in the enterprise, otherwise 0. IndepRatio is the proportion of independent directors in the board of directors. Board size (Bsize) is the logarithm of the board size. The shareholding ratio of the largest shareholder (Top1) is the shareholding ratio of the controlling shareholder.

3.3. Model Setting

In order to test the impact of enterprise environmental protection expenditure on green innovation, the econometric model of this study is set as follows:

$$\text{GIapply\_strat}_{i,t} = \alpha_0 + \alpha_1 \cdot \text{env}_{i,t} + \sum \alpha_k \cdot \text{controls}_{i,t} + \tau_i + \gamma_t + \epsilon_{i,t} \tag{1}$$

$$\text{GIapply\_sub}_{i,t} = \beta_0 + \beta_1 \cdot \text{env}_{i,t} + \sum \beta_k \cdot \text{controls}_{i,t} + \tau_i + \gamma_t + \epsilon_{i,t} \tag{2}$$

Where i represents the enterprise and t represents the year. The explanatory variables are strategic Green Innovation $\text{GIapply\_strat}_{i,t}$ and substantive Green Innovation $\text{GIapply\_sub}_{i,t}$, and the explanatory variable is environmental protection expenditure (env). The positive and negative values of α_1 and β_1 are used to identify the effect of environmental protection expenditure on strategic green innovation and substantive green innovation. Controls are all possible control variables. In order to control the sample enterprises from the impact of time changes and the economic impact at the macro level, this study adds the fixed effect at the enterprise level and the fixed effect at the time level to form a two-way fixed effect model.

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4. Empirical Results and Analysis

4.1. Benchmark Regression Results

According to the setting of the above benchmark model, this study uses the two-way fixed effect model for empirical test, and the regression results are shown in Table 2. Panel A in Table 2 is the regression result of enterprise environmental protection expenditure on strategic green innovation. Column (1) reports the estimated results excluding control variables, and columns (2), (3) and (4) gradually add control variables. It should be pointed out that all models control the fixed effect of individual and year. The regression results of environmental protection expenditure and strategic green innovation of enterprises are shown in column (1) of Table 2. The results show that the coefficient of environmental protection expenditure of enterprises is significantly positive at the level of 1%. After gradually adding control variables, the change of regression coefficient is not affected, and the regression result of environmental protection expenditure of enterprises on strategic green innovation is always 0.541. This shows that the investment of enterprises' environmental protection expenditure can promote enterprises to carry out strategic green innovation, and hypothesis 1a is verified.

Panel B is the regression result of corporate environmental protection expenditure on substantive green innovation. Column (1) reports the estimated results excluding the control variables, and columns (2), (3) and (4) also add the control variables step by step. The results show that although the coefficient of environmental protection expenditure of enterprises has declined, it is always significantly positive at the level of 1%. This shows that the investment of environmental protection expenditure of enterprises can promote the substantial green innovation of enterprises, and hypothesis 1b is verified. Table 2 shows that the environmental protection expenditure of enterprises will promote green innovation whether or not control variables are added.

Table 2. Benchmark Regression Results.

Panel A				
	(1) GIapply_strat	(2) GIapply_strat	(3) GIapply_strat	(4) GIapply_strat
env	0.693***	0.541***	0.541***	0.541***
	(0.068)	(0.066)	(0.066)	(0.066)
size		0.246***	0.246***	0.247***
		(0.011)	(0.011)	(0.011)
lev		-0.021	-0.024	-0.024
		(0.033)	(0.033)	(0.033)
ED		0.027***	0.027***	0.027***
		(0.008)	(0.008)	(0.008)
CD		-0.004***	-0.004***	-0.004***
		(0.001)	(0.001)	(0.001)
SOE			0.026	0.029
			(0.025)	(0.025)
Dual			-0.011	-0.012
			(0.012)	(0.012)
IndepRatio				0.236*
				(0.135)
BSize				0.022
				(0.042)
Top1				0
				(0.001)
Id FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	29520	29520	29520	29520
adj. R^2	0.683	0.692	0.692	0.692

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Table 2. *Cont.*

Panel B				
	(1) GIapply_sub	(2) GIapply_sub	(3) GIapply_sub	(4) GIapply_sub
env	0.622***	0.450***	0.453***	0.453***
	(0.067)	(0.066)	(0.066)	(0.066)
size		0.280***	0.280***	0.279***
		(0.011)	(0.011)	(0.011)
lev		-0.078**	-0.078**	-0.077**
		(0.033)	(0.033)	(0.033)
ED		0.023**	0.022**	0.022**
		(0.010)	(0.010)	(0.010)
CD		-0.004***	-0.004***	-0.004***
		(0.001)	(0.001)	(0.001)
SOE			0.034	0.034
			(0.027)	(0.027)
Dual			0.047***	0.047***
			(0.012)	(0.012)
IndepRatio				0.198
				(0.127)
BSize				0.069
				(0.043)
Top1				0
				(0.001)
Id FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	29520	29520	29520	29520
adj. R^2	0.706	0.717	0.717	0.717

Note: The standard error is in parentheses, and *** represents significance at the 1% statistical level.

4.2. Robustness Test

4.2.1. Adjusting the Measurement Method of Explanatory Variables

In order to ensure the robustness of the research results, this paper changes the calculation method of the explanatory variable enterprise environmental protection expenditure. On the one hand, the sum of the project amount in the "construction in progress" is divided by the total assets of the enterprise at the end of the current period, that is, the ratio of capitalized environmental protection investment to total assets (env_asset) is used as the proxy variable of environmental protection expenditure, and the two-way fixed effect model is used for regression. Results as shown in columns (1) and (2) of Table 3, on the basis of controlling the year and individual effect, the estimation coefficients of enterprise environmental protection expenditure env_asset for strategic green innovation and substantive green innovation are significantly positive at the level of 1%, which are 0.014 and 0.013 respectively. On the other hand, the environmental protection related items and the projects under construction in the details of "management expenses" in the enterprise's annual financial statements are summed up to obtain a more sufficient amount of environmental protection expenditure. The sum is treated as a logarithm (env_mgt) to calculate the environmental protection expenditure, and then re regressed. As shown in columns (3) and (4) of Table 3, the estimation coefficients of enterprise environmental protection expenditure env_asset for strategic green innovation and substantive green innovation are significantly positive at the level of 1%, which are 0.467 and 0.391 respectively. The results show that enterprise environmental protection expenditure can significantly promote green innovation activities. After replacing the explanatory variables, the results of this study are still robust.

Table 3. Results of Replacing Explanatory Variables.

	(1) GIapply_strat	(2) GIapply_sub	(3) GIapply_strat	(4) GIapply_sub
env_asset	0.014***	0.013***		
	(0.003)	(0.003)		
env_mgt			0.467***	0.391***
			(0.069)	(0.069)
controls	YES	YES	YES	YES
Id FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	29520	29520	29520	29520
adj. R^2	0.692	0.716	0.692	0.717

Note: The standard error is in parentheses, and *** represents significance at the 1% statistical level.

4.2.2. Adopt Higher Dimensional Fixed Effect

After replacing the explanatory variables, this study recalculates the explanatory variables strategic green innovation and substantive green innovation. Specifically, for strategic green innovation, the number of green utility model and design patents is used as the measurement index, and for substantive green innovation, the number of green invention patents is used as the measurement index. The regression results are shown in columns (1) and (2) of Table 4. The environmental protection expenditure of enterprises is still positive at the significance level of 1% for strategic green innovation and substantive green innovation, and the coefficients are 0.502 and 0.208 respectively. This shows that environmental protection expenditure can promote green innovation of enterprises. Columns (3) and (4) adopt a more stringent fixed effect, which not only controls the individual fixed effect, but also adds the fixed effect of industry and year. The results show that the env coefficients of enterprise environmental protection expenditure are 0.454 and 0.404, which are positive at the significance level of 1%. This shows that the results of this study are robust.

Table 4. Results with Different Fixed Effects Specifications.

	(1) GIauth_strat	(2) GIauth_sub	(3) GIapply_strat	(4) GIapply_sub
env	0.502***	0.208***	0.454***	0.404***
	(0.067)	(0.050)	(0.066)	(0.066)
controls	YES	YES	YES	YES
Id FE	YES	YES	YES	YES
Year FE	YES	YES	NO	NO
Ind×Year FE	NO	NO	YES	YES
N	29520	29520	29471	29471
adj. R^2	0.683	0.665	0.706	0.728

Note: The standard error is in parentheses, and *** represents significance at the 1% statistical level.

4.2.3. Endogenous Problems

Since the motivation and ability of enterprises' own innovation is a possible driving force for enterprises to increase their investment in environmental protection, there may be a reverse causal relationship between enterprises' environmental protection expenditure and strategic green innovation and substantive green innovation. At the same time, there are many factors that affect the green innovation of enterprises, and this study may omit important variables. In order to solve this endogenous problem, this study uses the instrumental variable method. The average value of various environmental protection expenditures at the provincial industry year level is mainly used as the instrument variable (env_iv). This instrumental variable will, to a certain extent, affect the amount of investment in environmental protection expenditure in the same year, that is, when the environmental protection expenditure of the same industry and province in the same year increases, the corresponding amount of environmental protection expenditure of enterprises will increase. However, this tool variable is not directly related to the green innovation of enterprises, and the green innovation results of enterprises in the same year will not change the environmental protection expenditure of industrial provinces in the same year. Therefore, this study selected the provincial industry environmental protection expenditure in the same period as the enterprise environmental protection expenditure as the tool variable for endogenous test.

Table 5 shows the results of the instrumental variable method. Column (1) shows the regression results of the first stage with the environmental protection expenditure of enterprises as the explained variable and the instrumental variable env_iv as the explanatory variable. The fitting value obtained is substituted into the second stage for the regression of strategic green innovation and substantive green innovation. Columns (2) and (3) show that when the instrumental variable is used for regression, the environmental protection expenditure is significantly positive at the level of 1%, which is consistent with the results of the previous benchmark regression. At the same time, the statistics of the weak instrumental variable test in the first stage are far greater than the critical value, so there is no problem of unidentifiable and weak instrumental variables in this study. The results in Table 5 show that the conclusion of this study is still robust after solving the endogenous problem.

Table 5. IV Regression Results.

	(1) env	(2) GIapply_strat	(3) GIapply_sub
env_iv	0.906*** (0.009)		
env		0.607*** (0.152)	0.400*** (0.149)
controls	YES	YES	YES
Id FE	YES	YES	YES
Year FE	YES	YES	YES
Wald F statistic		7073.037	7073.037
LM statistic		727.022	727.022
N	29520	29520	29520
adj. R^2	0.643	0.034	0.041

Note: The standard error is in parentheses, and *** represents significance at the 1% statistical level.

5. Analysis of Signal Transmission Mechanism

In order to verify the signal transmission mechanism of enterprise environmental protection expenditure, this study introduces new variables. Existing literature shows that venture capital is conducive to promoting the innovation activities of enterprises [28]. At the same time, as of 2012, China's venture capital management funds have exceeded 2trillion yuan. When the environmental protection expenditure of enterprises has a signal transmission mechanism, the venture capital obtained by enterprises will be one of the important sources of funds. Venture capitalists receive positive signals from enterprises, so as to increase support for green innovation of enterprises. Therefore, this study uses the dummy variable of venture capital as the proxy index. Specifically, for the listed companies in the sample, find out whether the top ten shareholders of the enterprise include branch investment institutions, so as to judge whether the enterprise is affirmed and supported by venture capital. From the statistical data, 6518 A-share listed companies obtained venture capital from 2012 to 2023, accounting for 21.8% of the total sample. In order to verify the signal transmission mechanism of environmental protection expenditure, the following model was constructed in this study:

$$\text{env}_{i,t} = \alpha_0 + \alpha_1 \cdot \text{vc\_dummy}_{i,t} + \sum \alpha_k \cdot \text{controls}_{i,t} + \tau_i + \theta_t + \epsilon_{i,t} \tag{3}$$

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$$\text{GIapply\_strat}_{i,t} = \beta_0 + \beta_1 \cdot \text{env}_{i,t} + \beta_2 \cdot \text{vc\_dummy}_{i,t} + \sum \beta_k \cdot \text{controls}_{i,t} + \tau_i + \theta_t + \epsilon_{i,t} \quad (4)$$

$$\text{GIapply\_sub}_{i,t} = \gamma_0 + \gamma_1 \cdot \text{env}_{i,t} + \gamma_2 \cdot \text{vc\_dummy}_{i,t} + \sum \gamma_k \cdot \text{controls}_{i,t} + \tau_i + \theta_t + \epsilon_{i,t} \quad (5)$$

Where $vc\_dummy_{i,t}$ is a dummy variable and env is the explanatory variable environmental protection expenditure, which controls the two-way fixed effect of individual and year. The regression results are shown in columns (1), (2) and (3) of Table 6. Column (1) shows that the coefficient between environmental protection expenditure and venture capital is 0.070, which indicates that enterprises' environmental protection expenditure will enhance the support of venture capital. Column (2) and column (3) respectively add venture capital to the regression of enterprise green innovation. The results show that the significance level of both are positive at 1%, and the coefficients are 0.449 and 0.539 respectively. It can be concluded that venture capital is conducive to promoting enterprise strategic green innovation and substantive Green Innovation.

In order to make the results more convincing, this study also calculates how many analysts or analysis teams the enterprise obtained in that year, so the variable attention is introduced. This variable is measured by the natural logarithm of the number of analysts or teams who analyze the enterprise. The research reports issued by analysts and teams to a certain extent represent the attention of the external environment to the enterprise. The more attention, the more social resources available to the enterprise will increase accordingly, so that the enterprise is easier to obtain external financial support and cooperation channels. The results are shown in columns (4), (5) and (6) of Table 6. Column (4) shows that enterprises' investment in environmental protection will get the attention of analysts, and the increase of attention, as shown in columns (5) and (6), the coefficients are significantly positive at the level of 1%, which indicates that analysts' attention can better promote enterprises' strategic green innovation and substantive green innovation, and H2a and H2b are verified. The results further show that the signaling mechanism of enterprise environmental protection expenditure does exist.

Table 6. Regression Results with Different Models

	(1) vc_dummy	(2) GIapply_sub	(3) GIapply_strat	(4) Attention	(5) GIapply_sub	(6) GIapply_strat
env	0.070**	0.449***	0.539***	2.233***	0.312***	0.280***
	(0.034)	(0.066)	(0.066)	(0.084)	(0.066)	(0.065)
vc_dummy		0.047***	0.031**			
		(0.012)	(0.012)			
Attention					0.063***	0.117***
					(0.005)	(0.005)
controls	YES	YES	YES	YES	YES	YES
Id FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
N	29520	29520	29520	29520	29520	29520
adj. R^2	0.490	0.717	0.692	0.660	0.719	0.699

Note: The standard error is in parentheses, and *** represents significance at the 1% statistical level.

6. Further Analysis

6.1. Heterogeneity Analysis

1. Enterprise life cycle. Enterprises in different life cycle stages will have different vitality and intensity of green innovation, so the promotion effect of environmental protection expenditure invested by enterprises on green innovation is also different. This study refers to Dickinson [29] and divides the life cycle according to the cash flow of the enterprise. It defines the enterprise stage by the positive and negative sign combination of cash flow from operating activities (CFO), cash flow from investing activities (CFI) and cash flow from financing activities (CFF), which is divided into growth stage and maturity stage.

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The results in Table 7 show that the promotion effect of environmental protection expenditure on strategic green innovation and substantive green innovation behavior of sample companies in the growth period is significantly positive, but the promotion effect of environmental protection expenditure on enterprises in the mature period is not obvious. This is because the growing enterprises are in the stage of rapid expansion, and their financing ability is strong, providing sufficient financial support for environmental protection expenditure. Compared with mature enterprises, growing enterprises have higher organizational flexibility and technology absorption capacity, and can quickly transform environmental protection investment into green technology research and development and green management system optimization.

Table 7. Regression Results for Different Stages.

	Growth Stage		**Maturity Stage**	
	(1) GIapply_strat	(2) GIapply_strat	(3) GIapply_sub	(4) GIapply_sub
env	0.563***	-0.041	0.443***	0.316
	(0.070)	(0.239)	(0.069)	(0.248)
controls	YES	YES	YES	YES
Id FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	27219	1805	27219	1805
adj. R^2	0.695	0.592	0.720	0.633

Note: The standard error is in parentheses, and *** represents significance at the 1% statistical level.

2. Corporate financing constraints. The differences of financing constraints faced by enterprises will significantly affect their resource allocation strategies and innovation behavior choices. As for the relationship between environmental protection expenditure and green innovation, enterprises with high financing constraints may prefer to give priority to meeting short-term survival needs and curb long-term green technology investment due to the high cost of external financing; Enterprises with low financing constraints have sufficient internal and external financial support, which can more flexibly transform environmental protection expenditure into substantive innovation activities. To accurately characterize this heterogeneity, this study uses the SA index proposed by Hadlock and Pierce [30] to measure the level of financing constraints. In the specific calculation, the larger the SA index value, the higher the degree of financing constraints. Based on this, the sample is divided into high and low financing constraints groups, which can effectively test how the effect of environmental protection expenditure on green innovation changes dynamically with the financing ability of enterprises.
The results in Table 8 show that environmental protection expenditure has a significant positive impact on strategic green innovation and substantive green innovation, but the effect of the low financing constraint group is significantly higher than that of the high financing constraint group. This difference is due to the fact that enterprises with low financing constraints have sufficient internal cash flow and external financing channels, which can break through the capital intensive constraints of green innovation. Its environmental protection expenditure can simultaneously support short-term compliance oriented green certification, that is, strategic green innovation and R&D investment of long-term technology accumulation, that is, substantive green innovation. However, enterprises with high financing constraints are forced to trade-off between the two types of innovation due to lack of funds to inhibit the overall utility.

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Table 8. Regression Results for High and Low Groups

	High		**Low**	
	(1) GIapply_strat	(2) GIapply_strat	(3) GIapply_sub	(4) GIapply_sub
env	0.342***	0.641***	0.400***	0.424***
	(0.106)	(0.094)	(0.103)	(0.094)
	(0.001)	(0.001)	(0.001)	(0.001)
controls	YES	YES	YES	YES
Id FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	14514	14561	14514	14561
adj. R^2	0.741	0.680	0.767	0.700

Note: The standard error is in parentheses, and *** represents significance at the 1% statistical level.

3. Enterprise size. As the core representation of resource allocation ability and market power, enterprise scale has a profound impact on the implementation efficiency of its environmental strategy. Large scale enterprises usually have stronger capital reserves, technology accumulation and policy lobbying ability, can dilute the fixed cost of green innovation through economies of scale effect, and obtain more government subsidies or green certification opportunities with the help of market position; Due to resource constraints, small-scale enterprises may rely more on flexibility advantages to focus on differentiated green technology breakthroughs. In order to accurately capture the heterogeneity of scale, this study uses total assets to divide the sample enterprises into large-scale enterprises and small-scale enterprises, so as to test whether the effect of environmental protection expenditure on green innovation is structurally different due to the size of enterprises.
   The regression results in Table 9 show that environmental protection expenditure can significantly promote strategic green innovation (coefficient=0.592, p<0.01) and substantive green innovation (coefficient=0.588, p<0.01) of large-scale enterprises, while only strategic innovation of small-scale enterprises is significant (coefficient=0.193, p<0.1). This heterogeneous result shows that large-scale enterprises with strong asset base can share the fixed costs of green innovation through economies of scale, and their environmental protection expenditure can support both compliance oriented strategic green innovation and technology breakthrough oriented substantive green innovation. However, small-scale enterprises are limited by capital and talent reserves, and environmental protection investment is more used to meet basic compliance requirements, which is difficult to support long-term and high-risk substantive green innovation.

Table 9. Regression Results for Large and Small Groups

	Large		**Small**	
	(1) GIapply_strat	(2) GIapply_strat	(3) GIapply_sub	(4) GIapply_sub
env	0.592***	0.193**	0.588***	0.094
	(0.098)	(0.087)	(0.099)	(0.082)
controls	YES	YES	YES	YES
Id FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	14712	14488	14712	14488
adj. R^2	0.743	0.529	0.765	0.569

Note: The standard error is in parentheses, and *** represents significance at the 1% statistical level.

6.2. Impact on Economic Performance

In order to verify the significance of strategic green innovation and substantive green innovation, this study further explores the impact of two different types of green innovation on enterprise economic performance. The economic performance is measured by the rate of return on total assets and Tobin

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Q, where ROA is calculated by the ratio of net profit to total assets, and Tobin Q is calculated by the ratio of market value to total assets. The results are shown in Table 10. Columns (1) and (2) show that the strategic green innovation and substantive green innovation of enterprises are positive at the significance level of 1%, that is, both types of green innovation effectively promote the return on total assets. The regression results of columns (3) and (4) show that the strategic green innovation and substantive green innovation of enterprises are positive to tobinq coefficient at the level of 5%, which proves that both types of green innovation effectively promote tobinq. However, compared with strategic green innovation, substantive green innovation plays a greater role in promoting.

Table 10. Regression Results for ROA and Tobin's Q

	(1) ROA	(2) ROA	(3) TobinQ	(4) TobinQ
GIapply_strat	0.027***		0.230**	
	(0.001)		(0.098)	
GIapply_sub		0.008***		0.269**
		(0.001)		(0.115)
controls	YES	YES	YES	YES
Id FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	29520	29520	29520	29520
adj. R^2	0.350	0.325	0.197	0.197

Note: The standard error is in parentheses, and *** represents significance at the 1% statistical level.

7. Conclusions and Policy Recommendations

7.1. Research Conclusion

By analyzing the data of A-share listed companies in Shanghai and Shenzhen, this study reveals the multi-level impact of environmental protection expenditure on green innovation and its internal mechanism. First, environmental protection expenditure not only directly promotes green innovation, but also significantly strengthens this role through the signaling mechanism. Specifically, enterprises release their commitment to sustainable development to the outside world by increasing environmental protection investment, attract more social resources and gain the trust of investors, thus providing dual impetus for strategic green innovation and substantive green innovation. This finding confirms that environmental protection expenditure is not only the material basis for technology upgrading, but also the key signal tool for enterprises to build green reputation and leverage external resources.

Second, the innovation effect of environmental protection expenditure has significant heterogeneity. Large enterprises are more likely to achieve substantial innovation breakthroughs because of their resource integration ability, while small and medium-sized enterprises tend to strategic innovation under financing constraints and survival pressure. Enterprises in the growth stage rely on the signal effect of environmental protection investment to obtain external support, while enterprises in the mature stage pay more attention to technology upgrading through internal R&D. These differences show that the innovation and transformation efficiency of environmental protection expenditure highly depends on the matching degree between the enterprise's own endowment and the external environment.

7.2. Policy Recommendations

In order to maximize the driving force of environmental protection expenditure on green innovation, policy-making needs to shift from "single constraint" to a systematic framework of "incentive signal empowerment".

First of all, we should optimize the policy mix of environmental regulation, establish a "step-by-step" regulation standard, give leading enterprises in environmental protection technology a longer compliance buffer period and a higher proportion of R&D subsidies, and gradually punish enterprises with lagging technology to avoid the innovation inhibition caused by the "one size fits all" policy.

Secondly, it is necessary to strengthen the signal transmission function of environmental protection investment, force enterprises to disclose the details of environmental protection investment and innovation output by improving the ESG information disclosure system, and introduce a third-party certification mechanism to eliminate the "green drift" behavior, so as to enhance the market's ability to identify and respond to green signals. For example, it can promote environmental protection investment and green patent pledge financing, encourage financial institutions to develop financial products linked to innovation performance, and effectively transform the green commitment of enterprises into financing cost advantages. For the heterogeneity of enterprises, the policy should implement precise intervention. For large-scale enterprises, support them to take the lead in establishing industry green technology alliance, and drive industrial chain innovation through technology spillover. For small and medium-sized enterprises, it is necessary to reduce the trial and error cost of green technology, set up a special fund to cover the initial investment in the upgrading of environmental protection equipment, and simplify the green credit approval process to ease the financing constraints.

In addition, the government needs to build an industry university research collaboration platform, integrate the technical needs of universities, scientific research institutions and enterprises, accelerate the transformation of environmental protection technology from laboratory to commercialization, and pay special attention to the technology adaptation of growing enterprises. Finally, it is suggested to introduce "innovation friendly" regulatory tools, such as the pilot mechanism of "replacing innovation credits with emission quotas" in high-tech parks, allowing enterprises to deduct part of the emission quotas through green patent output, so as to stimulate the endogenous enthusiasm of enterprises to transform environmental pressure into innovation power. Through the above-mentioned multidimensional policy coordination, the technology dividends of enterprises' environmental protection investment can be released while protecting the ecological environment objectives, providing micro support for China's "double carbon" strategy and high-quality development.

7.3. Research Deficiencies and Prospects

Although this study systematically discusses the impact mechanism and policy implications of enterprise environmental protection expenditure on green innovation, there are still some limitations. First of all, at the data level, the environmental protection investment data obtained through keyword screening and manual collection in the annual report may be affected by the integrity of enterprise information disclosure and the difference in subjective expression. For example, some enterprises may include non environmental protection expenditures into environmental protection subjects to create a green image, resulting in measurement errors. Secondly, the verification of the signal transmission mechanism mainly relies on theoretical deduction and indirect evidence. The feedback behavior of the signal receiver has not been directly tracked. In the future, the explanatory power of the mechanism can be enhanced through questionnaire survey or text analysis.

Future research can expand the multidimensional measurement framework of environmental protection expenditure and improve the accuracy of variable construction. The dynamic perspective is introduced to explore the long-term interaction between environmental protection expenditure and green innovation. In addition to the signal transmission mechanism, we can explore the joint effect of enterprise endogenous power and external network embeddedness, and compare the relative importance of different mechanisms in different institutional environments.

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