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Green Finance 'Ignite' Corporate Low-Carbon Innovation: An Empirical Test Based on the Incentive Effect

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Abstract: Corporate environmental protection investment serves as a green financial instrument characterized by "endogenous" features. Based on data from A-share listed companies on the Shanghai and Shenzhen stock exchanges from 2010 to 2023, this study examines its impact on green technological innovation and the underlying mechanisms. The findings reveal that environmental protection investment exerts a significant positive incentive effect on corporate green technological innovation, and these conclusions remain robust after controlling for endogeneity. Mechanism tests indicate that financing constraints serve as the core transmission channel: environmental investment alleviates financing constraints through signalling, thereby promoting green innovation, while the R&D investment channel is not significant. Heterogeneity analysis reveals that this effect is more pronounced in non-state-owned enterprises and high-carbon industries. The study recommends incorporating corporate environmental investment into the green finance policy framework, strengthening information disclosure, and stimulating the endogenous momentum of corporate green transformation.

Keywords: Green finance; Environmental investment; Green technology innovation; Financing constraints; Nature of property rights

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1. Introduction

The transition to a green and low-carbon economy is central to China's high-quality development. As the "dual carbon" goals are advanced, enterprises, as the primary sources of carbon emissions and drivers of technological innovation, play a pivotal role in shaping the path toward achieving these objectives. Green finance is viewed with great optimism by policymakers; as of the third quarter of 2025, the outstanding balance of green loans in China (in both domestic and foreign currencies) had reached 43.51 trillion yuan, while the outstanding volume of green bonds stood at 2.46 trillion yuan, placing both figures among the highest globally [1,2]. However, there is still a lack of sufficient empirical evidence to show exactly how much substantive technological innovation has been driven by this expansion in scale.

Existing research has largely focused on "exogenous" financing instruments such as green loans and green bonds, while overlooking firms' internal green capital allocation practices [3,4]. Although firms allocate internal capital to environmental investments, such as pollution control and clean production, without relying on financial intermediaries, this constitutes a classic form of financial resource allocation. This paper defines such practices as "endogenous" green financial instruments. International research also provides support for this perspective [5].

Since green capital allocation, an inherent aspect of corporate decision-making, has long been overlooked, a number of key questions remain to be systematically addressed: Can environmental investments effectively incentivize low-carbon technological innovation in enterprises? Do they achieve this by alleviating financing constraints or by promoting R&D investment? Do their effects vary across different types of enterprises?

Based on the above considerations, this paper utilizes data on A-share listed companies on the Shanghai and Shenzhen stock exchanges from 2010 to 2023 to systematically examine the impact, transmission channels, and heterogeneous characteristics of environmental protection investment on green technological innovation. The study's marginal contributions include: overcoming the limitations of a perspective that "prioritizes external factors over internal ones" by defining environmental protection investment as an "endogenous" green financial instrument; clarifying its unique transmission mechanisms; and providing new evidence regarding the micro-level driving mechanisms of corporate green innovation.

2. Literature review and theoretical analysis

2.1. Environmental investment: An overlooked "endogenous" green finance tool

Existing research has largely focused on "exogenous" financing instruments such as green loans and green bonds [6,7]. However, the sources of funding for corporate green transformation are not limited to external financing. When firms allocate internal capital to environmental investments in areas such as pollution control and clean production, although these investments do not rely on financial intermediaries, they exhibit distinct characteristics of financial resource allocation. This paper defines such behavior as "endogenous" green financial instruments.

In recent years, environmental investment has attracted academic attention. Li *et al.* found that environmental investment mediates the relationship between environmental regulatory pressure and corporate green innovation [8]. Shi discovered synergies between heterogeneous environmental investment and digital empowerment [9]. Zhang and Zhao confirmed that pollutant emission assessments can promote both the quantity and quality of environmental investment [10]. However, few studies have placed environmental investment within a green finance analytical framework to systematically examine its direct incentive effects on green technological innovation.

2.2. Environmental investment and low-carbon technological innovation: Signalling and financing constraints

The relationship between environmental regulations and corporate innovation has been extensively discussed [11–13]. However, how does external pressure translate into internal corporate motivation? In this process, environmental investment serves as a crucial mediating variable.

Signalling theory provides an analytical framework for understanding the innovation effects of environmental investment. The observable and verifiable nature of environmental investment, subject to board review, recorded in financial statements, and audited by independent auditors, makes it a credible signal of a firm's green strategy. Based on this, we propose:

H1: Environmental investment has a significant positive incentive effect on a firm's low-carbon technology innovation.

Financing constraint theory further elucidates the economic consequences of signalling. Green technology innovation is characterized by long R&D cycles and high failure risks; the marginal promotional effect of alleviating financing constraints is particularly pronounced. Environmental investment alleviates financing constraints through signalling, thereby creating conditions for green innovation [14]. Based on this, we propose:

H2: Financing constraints are a key transmission channel through which environmental investment promotes low-carbon technology innovation; environmental investment enhances a firm's green innovation output by alleviating financing constraints.

2.3. The moderating effect of property rights and industry-specific carbon intensity

The nature of ownership is a key moderating variable influencing corporate green innovation. Existing research indicates that non-state-owned enterprises face stronger market competition and tighter budget constraints, making them more likely to allocate their environmental protection investments to R&D activities with the highest marginal returns [15,16]. Based on this, we propose:

H3: The innovation-inducing effect of environmental protection investment is more pronounced in non-state-owned enterprises.

Industry carbon intensity also constitutes an important moderating dimension. Existing literature demonstrates that high-carbon industries have long been subject to policy constraints such as emission reduction targets and dual controls on energy consumption. Compliance pressures have prompted firms to shift environmental investments from end-of-pipe treatment to technology R&D. Consequently, high-carbon industries have greater room for technological catch-up, a relatively weak foundation in green technology, and higher marginal innovation outputs from environmental investments [17].

H4: The innovation-inducing effect of environmental investment is more pronounced in high-carbon industries.

3. Research design

3.1. Sample selection and data sources

This study selects A-share listed companies on the Shanghai and Shenzhen stock exchanges from 2010 to 2023 as the initial sample. The choice of 2010 as the starting point is based on two key considerations: first, following the issuance of the "Green Credit Guidelines" in 2009, green finance policies entered a phase of systematic implementation; second, starting in 2010, the standardization of environmental information disclosure by listed companies improved significantly, leading to better data availability for variables such as environmental protection investments.

Sample selection criteria are as follows:

(1) Exclude listed companies in the finance and insurance sectors;
(2) Exclude ST, *ST, and PT-listed companies;
(3) Exclude observations with severe missing values for core variables;
(4) Trim all continuous variables at the 1% and 99% quantiles.

This resulted in a final dataset of 33,703 firm-year observations, covering 3,182 listed companies.

Environmental investment data was sourced from CSMAR's "Statistical Table of Environmental Investments by Listed Companies," using the "Environmental Investment" field directly. Green patent data was sourced from CSMAR's "Green Patent Research Database," calculated as the natural logarithm of the sum of the number of green invention patents and green utility model patents independently applied for and accepted by the firm in the given year, plus one. The financing constraint is measured using the SA index, calculated as $SA = -0.737 \times Size + 0.043 \times Size^2 - 0.04 \times Age$, with data sourced from CSMAR's "Business Distress Study." The instrumental variable is the average environmental investment intensity of other firms in the same industry during the same year. All other variables are sourced from the CSMAR database.

3.2. Variable definitions and measures

3.2.1. Dependent variable

Corporate green technology innovation (ln green patent). This is calculated as the natural logarithm of the sum of the number of green invention patents and green utility model patents independently applied for and accepted by the enterprise in the current year, plus one. A higher value for this indicator indicates stronger corporate green technology innovation capabilities.

3.2.2. Core explanatory variable

Environmental Investment (ln env invest). This is calculated as the natural logarithm of the enterprise's environmental-related capital expenditures for the current year, plus one. A higher value of this indicator indicates a greater intensity of resource allocation toward green transformation and serves as a metric for the "endogenous" green financial instruments defined in this paper.

3.2.3. Mechanism variable

Financing constraints are measured using the SA index, which is a negative indicator; a higher absolute value indicates a greater degree of financing constraints. R&D intensity is measured as the percentage of annual R&D expenditure relative to operating revenue.

3.2.4. Instrumental variable

We use the mean environmental investment intensity of other firms within the same industry and year. This variable satisfies the requirements of correlation and exogeneity: on the one hand, environmental investment by firms in the same industry exerts demonstration and competitive effects, making it highly correlated with the focal firm's environmental investment; on the other hand, environmental investment by other firms in the same industry does not directly influence the focal firm's green innovation output.

3.2.5. Heterogeneity grouping variable

A dummy variable is set based on the nature of ownership, with state-controlled enterprises assigned a value of 1 and non-state-controlled enterprises assigned a value of 0. Industry carbon intensity defines sectors such as coal mining, petroleum processing, chemical raw materials, non-metallic minerals, ferrous metal smelting, non-ferrous metal smelting, and electricity and heat supply as high-carbon industries,and assigned a value of 1; all others are classified as low-carbon industries [18].

3.2.6. Control variable

These include firm size (Size), debt-to-asset ratio (Leverage), return on assets (ROA), firm age (Firm age), and ownership structure (SOE). All regression models control for fixed effects of year, industry, and province. The definitions and measurement methods of the main variables are summarized in **Table 1**.

Table 1. Summary of variable definitions and measures

Variable type	Variable	Measurement methods
Dependent Variable	Ln green patent	Ln(1+Total number of green patent applications filed by the company that year)
Core Dependent Variable	Ln env invest	Ln(1+The company's environmental-related capital expenditures for the year). Specifically, the metrics for enterprises' "internal" green financial instruments
Mechanism Variable	SA	SA=-0.737×Size+0.043×Size^2-0.04×Age
Mechanism Variable	RD	R&D Expenditures / Revenue × 100
Grouping Variable	SOE	State-controlled = 1, Non-state-controlled = 0
Grouping Variable	High carbon	High-carbon industries = 1, low-carbon industries = 0
Control Variable	Size	Ln(Total assets)
Control Variable	Leverage	Total Liabilities / Total Assets
Control Variable	ROA	Net Income / Total Assets
Control Variable	Firm age	Ln(Observation Year – Year of Market Launch + 1)

3.3. Model specification

3.3.1. Baseline regression model

To examine the impact of environmental investment on corporate green technological innovation, this study constructs the following two-way fixed-effects model:

$$GeenPatit = \alpha 0 + \alpha 1 Env \ln vit + \gamma Xit + \lambda t + \delta j + \theta p + \varepsilon it \tag{1}$$

In **Equation (1)**，$GeenPatit$ represents the logarithm of firm i's green patent applications in year t (ln green patent)，$Env\ln vit$ represents the logarithm of environmental investment (ln env invest)，Xit is the vector of control variables, including firm size (size), debt-to-asset ratio (leverage), return on assets (roa), firm age, ownership type (soe).λt represents the year fixed effects,δj represents the industry fixed effects，θp represents the province fixed effects，εit represents the random disturbance term. The core parameter of interest in the baseline regression is $\partial 1$, with a positive sign.

It should be noted that the primary reason for not including firm-level fixed effects in this study is that the core explanatory variable, environmental investment, exhibits limited intra-firm time-series variation. Controlling for fixed effects at the firm, industry, province, and year levels simultaneously would result in severe multicollinearity, significantly reducing the precision of the core parameter estimates. Substituting firm-level fixed effects with industry- and province-level fixed effects is a common practice in micro-level firm innovation research when addressing similar issues. To mitigate heteroskedasticity and within-group correlation, all regression standard errors are cluster-adjusted at the firm level.

3.3.2. Testing the mechanism model

To test the mediating effects of financing constraints and R&D investment on the relationship between environmental protection investment and green innovation, this study employs a stepwise approach:

$$Mit = \beta 0 + \beta 1 Env \ln vit + \gamma Xit + \lambda t + \delta j + \theta p + \varepsilon it \tag{2}$$

$$GeenPatit = \eta 0 + \eta 1 Env \ln vit + \eta 2 Mit + \gamma Xit + \lambda t + \delta j + \theta p + \varepsilon it \tag{3}$$

In **Equation (2)**, Mit represents the mechanism variable, where the former denotes financing constraints (SA index) and the latter denotes R&D intensity (RD). $Env \ln vit$ represents the logarithm of environmental investment (ln env invest), Xit and represents the vector of control variables, with the same definitions as in the baseline regression model. λt 、 δj 、 θp represent fixed effects for year, industry, and province, respectively, εit is the random disturbance term.

If $\beta 1$ is significant and $\eta 2$ is significant, if the regression coefficient for $\eta 1$ decreases relative to the benchmark coefficient $\partial 1$ or becomes insignificant, this indicates the presence of a mediating effect. It should be noted that there are a significant number of missing values in the R&D intensity data; therefore, this path analysis was conducted using a subsample with complete R&D data. All regression standard errors were cluster-adjusted at the firm level.

3.3.3. Endogenous model

To address the potential issue of spurious causality between environmental investment and green innovation, this study employs the instrumental variables method to conduct a two-stage least squares (2SLS) estimation. The instrumental variable selected is the average environmental investment intensity of other firms in the same industry during the same year. The model is specified as follows:

$$Env \ln vit = \pi 0 + \pi 1 L.Env \ln vit + \gamma Xit + \lambda t + \delta j + \theta p + vit \tag{4}$$

$$GreenPatit = \alpha 0 + \alpha 1 Env \ln v_{it}^{IV} + \gamma Xit + \lambda t + \delta j + \theta p + \varepsilon it \tag{5}$$

In **Equation (4)**, $IV\mathrm{it}$ is the instrumental variable, representing the average environmental investment intensity of other firms in the same industry during the same year. $Env \ln vit$ is the logarithm of environmental investment (ln env invest), $X\mathrm{it}$ is the vector of control variables, including firm size, leverage, return on assets (ROA), firm age, and ownership type (SOE). λt 、 δj 、 θp represent fixed effects for year, industry, and province, respectively, while εit is the random disturbance term.

In the first-stage regression, if the F-statistic exceeds the empirical threshold of 10, it is concluded that there is no weak instrumental variable problem, and the Durbin-Wu-Hausman test can then be used to assess the endogeneity of environmental investment.

Standard errors for all regression models are cluster-adjusted at the firm level, and fixed effects are specified in exactly the same manner as in the baseline regression. Model estimation was performed using Stata 18. To ensure the reproducibility of the results, the complete data processing code and estimation procedures have been archived for reference.

4. Analysis of empirical results

The theoretical section above proposed four research hypotheses to be tested: environmental investment has a positive incentive effect on green technological innovation (H1); financing constraints are the core transmission mechanism (H2); this effect is more pronounced in non-state-owned enterprises (H3); and it is also more pronounced in high-carbon industries (H4). This section will empirically test the above hypotheses using a two-way fixed-effects model and will properly address the endogeneity issue in the robustness analysis using the instrumental variables method.

4.1. Descriptive statistics

Table 2 presents the descriptive statistics for the main variables. The sample period spans from 2010 to 2023, and the study focuses on A-share listed companies. After data cleaning, a total of 33,703 firm-year observations were obtained. Due to a high number of missing values in the R&D expenditure data, only 10,680 valid observations were retained for the mechanism testing section.

Table 2. Descriptive statistics

Variable name	Variable	Observation	Mean	Standard deviation	Minimum	Maximum
Green Patents	ln green patent	33703	0.830	1.152	0.000	4.673
Environmental Investment	ln env invest	34494	0.685	2.275	0.000	16.189
Financing Constraints	sa-index	19940	-3.837	0.289	-5.835	-0.271
R&D Intensity	rd intensity	10680	0.035	0.043	0.000	0.265
Company Size	size	33703	22.272	1.291	19.918	26.282
Debt-to-Equity Ratio	leverage	33703	0.429	0.205	0.057	0.902
Return on Total Assets	roa	33703	0.036	0.063	-0.257	0.198
Company Age	firm age	33703	18.877	6.208	1.000	68.000
Ownership Structure	soe	33703	0.100	0.300	0.000	1.000
Share of Green Credit	green loan ratio	33703	0.101	0.024	0.056	0.154

Looking at the distribution of the instrumental variable, its mean is 0.683 and its standard deviation is 1.892, which is largely consistent with that of the environmental investment variable, suggesting a preliminary correlation between the two.

The mean of the logarithm of green patent applications is 0.830, with a standard deviation of 1.152, indicating significant differences in green innovation levels among enterprises. The mean of the logarithm of environmental investment is 0.685, with a standard deviation of 2.275; the distribution is right-skewed, suggesting that most enterprises have limited investment scales, while a few invest substantially. The mean of the SA index is -3.837 with a standard deviation of 0.289, ranging from -5.835 to -0.271. As a negative indicator, a lower value indicates more severe financing constraints. The mean R&D intensity is 3.5% with a standard deviation of 4.3%; approximately 69% of the observations are missing.

The distribution characteristics of the control variables are consistent with existing research, indicating good sample representativeness.

4.2. Baseline regression results

Table 3 presents the baseline estimates of the effect of environmental investment on green technological innovation. The model employs a two-way fixed-effects design to control for unobservable factors that do not vary over time at the year, industry, and provincial levels.

The coefficient for environmental protection investment is 0.0172, which is significant at the 1% level and remains stable across different model specifications. In economic terms, a one-standard-deviation increase (2.275) in environmental protection investment leads to an approximate 3.91% increase in green patent applications, equivalent to 4.7% of the sample mean. The methodology for measuring green innovation efficiency draws on the research by Qian *et al.* [19].

Table 3. Benchmark regression results

Variable	ln green patent
Ln env invest	0.0172***
	(0.0024)
size	0.4271***
	(0.0050)
leverage	0.0872***
	(0.0315)
roa	-0.2121**
	(0.0853)
Firm age	-0.0028***
	(0.0009)
soe	0.2066***
	(0.0174)
Constant	-9.5117***
	(0.2341)
Year FE	Yes
Industry FE	Yes
Province FE	Yes
N	33703
r2	0.452

Note: Standard errors in parentheses are robust;*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Regarding control variables, the coefficient for firm size was significantly positive, indicating that large firms possess a resource advantage in green technology R&D; the coefficient for debt-to-equity ratio was significantly positive, suggesting that debt financing supports firms' green innovation; the coefficient for return on total assets was significantly negative, implying that firms with higher profitability face relatively less pressure to transition; the coefficient for firm age was significantly negative, indicating that younger firms have stronger innovation momentum; and the coefficient for state-owned enterprises was significantly positive, consistent with the environmental policy responsibilities they bear. The model's goodness-of-fit is 0.452. The benchmark regression results support Hypothesis H1.

4.3. Mechanism testing

The previous analysis indicates that environmental investment has a significant positive impact on firms' green technological innovation. The next question is: through which channels does this effect occur? To answer this question, this paper examines the mechanism of environmental investment by focusing on two pathways: financing constraints and R&D investment.

4.3.1. Financing constraints path

Table 4 presents the results of the test on the financing constraint mechanism. The dependent variable is the SA index, which is a negative indicator; a higher value implies that firms face lower levels of financing constraints. The estimated coefficient for environmental investment (ln env invest) is 0.0045, which is significant at the 1% level. This result indicates that environmental investment plays a significant role in alleviating firms' financing constraints.

As an observable commitment to a firm's environmental strategy, environmental investment sends a dual signal to capital markets regarding the firm's determination to undergo a green transition and its ongoing funding needs. This helps reduce information asymmetry, improve credit availability, lower financing costs, and provide financial support for green innovation. Existing research has demonstrated that ESG ratings can alleviate financing constraints through signalling mechanisms, which aligns with the findings of this study and validates the transmission chain of "environmental investment–alleviation of financing constraints–green innovation [20]."

4.3.2. R&D investment pathway

Column (3) of **Table 4** presents the results of the test on the R&D investment mechanism. With R&D intensity as the dependent variable, the estimated coefficient for environmental protection investment is approximately 0.0001, which fails the significance test. This finding is inconsistent with the traditional theoretical expectation of the "financial support–increased R&D–innovation output" mechanism.

There are three possible reasons why the R&D investment pathway is not significant as follows:

(1) Environmental protection investment possesses the attribute of "targeted innovation." Although expenditures on activities such as the introduction of clean production technologies and process upgrades are not included in R&D expenses, the nature of these technological improvements is essentially no different from innovation;

(2) Given that enterprises have limited internal R&D resources, an expansion of environmental protection investment may shift some resources from basic research to applied technology development, causing traditional R&D intensity indicators to decline while redirecting innovation resources toward green technology fields;

(3) The equipment upgrades and process improvements resulting from environmental protection investment can enhance R&D efficiency, supporting the generation of more green patents without an increase in investment scale.

Table 4. Results of the mechanism test

Variable	Financing Constraints-SA Index	R&D intensity
Ln env invest	0.0045***	0.0000
	(0.0004)	(0.0001)
size	0.0321***	-0.0010***
	(0.0012)	(0.0003)
leverage	-0.1184***	-0.0510***
	(0.0078)	(0.0021)
Constant	-3.8235***	0.0692**
	(0.0507)	(0.0318)

Year FE	Yes	Yes
Industry FE	Yes	Yes
Province FE	Yes	Yes
N	19940	10219
r2	0.810	0.512

Note: Figures in parentheses represent robust standard errors; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The above analysis indicates that the fundamental mechanism through which environmental investment promotes green innovation lies in alleviating financing constraints rather than expanding R&D investment, a finding consistent with relevant international research. As an endogenous green financial instrument, environmental investment possesses observable and verifiable characteristics that not only help mitigate information asymmetry in debt financing but also send reliable signals regarding corporate green strategies to the equity market, thereby attracting sustainability-oriented investors. This multidimensional signalling function constitutes a significant institutional advantage that distinguishes it from exogenous instruments. The empirical results support the hypothesis that financing constraints serve as the core transmission mechanism, thereby confirming Hypothesis H2.

It should be noted that the R&D intensity variable has a high rate of missing values (approximately 69.7%); therefore, the mechanism tests were conducted only on a subsample with complete R&D data. Although this subsample does not differ significantly from the full sample in terms of key characteristics, selection bias may still exist, and caution is warranted when interpreting the relevant conclusions.

4.4. Heterogeneity analysis

Does the positive incentive effect of environmental investment on green technological innovation vary systematically across firms with different characteristics? Clarifying this issue helps define the scope of environmental investment and provides a basis for designing differentiated policies. This paper examines heterogeneity across two dimensions: ownership structure and industry carbon intensity.

4.4.1. Grouped analysis based on property rights nature

To test Hypothesis H3, this study conducts a grouped regression analysis based on ownership structure. State-owned enterprises have an inherent institutional link with the government and enjoy advantages in areas such as credit and subsidies; non-state-owned enterprises, on the other hand, have long been constrained by financing barriers and are more sensitive to market signals in their investment decisions. Therefore, the signalling function of environmental investment and the efficiency of innovation conversion may vary depending on ownership structure.

The results in **Table 5** show that the coefficient for environmental investment in non-state-owned enterprises is 0.0202 ($p < 0.01$), while the coefficient for state-owned enterprises is 0.0018 and is not significant; the difference between the two coefficients is significant at the 1% level. This indicates that the promotional effect of environmental investment on green innovation is more pronounced in non-state-owned enterprises, thereby confirming Hypothesis H3.

Table 5. Analysis of heterogeneity in property rights

Variable	Non-state-owned enterprises	State-owned enterprise
Ln env invest	0.0202***	0.0018
	(0.0035)	(0.0070)
size	0.3987***	0.6022***
	(0.0068)	(0.0194)
leverage	0.2112***	-0.9565***
	(0.0425)	(0.1472)
Constant	-8.7941***	-12.1237***
	(0.3577)	(0.7373)
Year FE	Yes	Yes
Industry FE	Yes	Yes
Province FE	Yes	Yes
N	17,710	2,230
r2	0.414	0.683

Note: Standard errors in parentheses are robust estimates; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

For non-state-owned enterprises, this financing disadvantage is transformed into an incentive advantage. Due to long-standing credit discrimination, their commitments to environmental responsibility are difficult for external investors to discern. However, environmental investments, as observable and verifiable capital expenditures, serve as a clear signal of a company's green strategy, thereby reducing information asymmetry and alleviating financing constraints on green innovation. In contrast, for state-owned enterprises, the signalling value of environmental investments is significantly diminished due to government credit guarantees and soft budget constraints. Furthermore, their environmental investments often serve non-economic objectives such as employment stability and regional development, with innovation output being merely one variable in the decision-making function, resulting in limited stimulation of technological innovation.

These findings reveal a deep-seated issue in green finance policies regarding the dimension of property rights: private enterprises, which are most in need of financial support, are precisely the group with the highest efficiency in converting environmental investments into innovation; conversely, state-owned enterprises, which continue to receive preferential access to credit resources, have failed to effectively translate environmental investments into innovation outcomes. How to correct this misalignment is a challenge that green finance reform must address.

4.4.2. Grouped analysis based on industry carbon intensity

To test Hypothesis H4, this study conducts a grouped regression based on industry carbon intensity. High-carbon industries have long been subject to policy constraints such as emission reduction targets and dual-control of energy consumption; consequently, the urgency of their green transition is greater than that of low-carbon industries, and the innovation-stimulating effect of environmental investment is expected to be more pronounced.

The results in **Table 6** show that the coefficient for environmental investment in high-carbon industries is 0.0213 ($p < 0.01$), while that for low-carbon industries is 0.0143 ($p < 0.01$). The former is significantly higher than the latter, confirming Hypothesis H4.

Table 6. Analysis of heterogeneity in industry-specific carbon intensity

Variable	High-carbon industries	Low-carbon industries
Ln env invest	0.0213***	0.0143***
	(0.0053)	(0.0055)
size	0.4013***	0.4342***
	(0.0198)	(0.0158)
leverage	0.0872***	0.0991***
	(0.1161)	(0.0717)
soe	0.1869**	0.1967***
	(0.0945)	(0.0545)
Constant	-9.8337***	-9.6147***
	(0.4717)	(0.3789)
Year FE	Yes	Yes
Industry FE	Yes	Yes
Province FE	Yes	Yes
N	7701	26,002
r2	0.402	0.460

Note: Standard errors in parentheses are robust; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

High-carbon industries face stricter environmental regulations and greater transformation risks, resulting in higher marginal returns on environmental investments. Driven by both compliance pressures and the need for technological upgrades, companies are more inclined to allocate environmental investments toward R&D activities. At the same time, high-carbon industries have greater room for technological catch-up and a relatively weak foundation in green technology; the introduction of new technologies and equipment upgrades resulting from environmental investments can generate more significant marginal innovation outputs. In low-carbon industries, regulatory pressure is moderate, and environmental investments are more often driven by proactive strategic decisions; however, their green technology foundations are mature, leaving limited room for marginal improvement.

The policy implications of these findings are as follows: high-carbon industries should be the primary focus of targeted green finance policies, as they exhibit higher efficiency in converting environmental investments into innovation and generate greater social returns in terms of environmental benefits such as carbon emissions reductions. Allocating credit resources and fiscal subsidies toward green technology R&D in high-carbon industries aligns with both efficiency principles and equity considerations.

4.5. Robustness tests for the Tobit model

The baseline regression employs a linear panel fixed-effects model, the validity of which relies on the dependent variable being continuously distributed and free of systematic truncation. However, the number of green patent applications exhibits significant left-censoring, approximately 36% of observations are zero, accurately reflecting that some firms have not yet generated effective green innovation outputs. Although the linear model yields consistent estimates, it suffers from efficiency losses.

To test the sensitivity of the findings to the model specification, this study re-estimates the results using a Tobit model. This model is specifically designed to address the issue of lower-bound truncation in the dependent variable and can simultaneously capture the binary choice of whether a firm engages in green innovation and the continuous distribution of innovation output intensity, making it theoretically more consistent with the generation process of green patent data.

Table 7 shows that the coefficient for environmental investment is 0.0206 ($p < 0.01$), which is slightly larger than the 0.0172 from the baseline regression but maintains the same level of significance. This indicates that the promotional effect of environmental investment on green innovation remains robust even after accounting for left-censoring characteristics.

Table 7. Robustness tests for the Tobit model

Variable	**Green patents**
Ln env invest	0.0206*** (0.0044)
size	0.4251*** (0.0051)
leverage	0.0893*** (0.0318)
Constant	-27.0553 (1,289.2209)
Year FE	Yes
Industry FE	Yes
Province FE	Yes
N	33703
Pseudo R²	0.2097

Note: Standard errors in parentheses are robust; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The signs and significance levels of the control variables are consistent with those in the baseline regression. The coefficient for firm size is significantly positive, confirming the advantage of large firms in terms of green innovation resources; the coefficient for debt-to-asset ratio is significantly positive, consistent with the logic that green credit supports innovation; and the coefficient for ownership type is significantly positive, reflecting the innovation characteristics of state-owned enterprises driven by environmental policy responsibilities. The constant term is large but not significant, which is a common phenomenon in Tobit models and does not affect the estimation of core parameters. The pseudo-R^2 is 0.2097, which falls within the empirical range of similar studies.

Overall, whether using a linear panel fixed-effects model for regression or a Tobit model to address truncation issues, the positive incentive effect of environmental investment on green technological innovation is statistically significant and economically substantial. The core conclusions are not sensitive to the specific model specification, demonstrating strong robustness.

4.6. Endogeneity tests

Benchmark regression, mechanism tests, and heterogeneity analysis confirm the positive impact of environmental investment on green innovation, and these findings have passed robustness tests such as the Tobit model. However, there may be a bidirectional causal relationship between environmental investment and green innovation. To address this, this study employs the instrumental variables method to conduct two-stage least squares (2SLS) estimation.

The average environmental investment intensity of other firms in the same industry and year is selected as the instrumental variable. Regarding correlation, environmental investment by firms in the same industry exerts demonstration and competitive effects and is highly correlated with the endogenous variable; regarding exogeneity, environmental investment by other firms in the same industry does not directly affect the green innovation output of the focal firm, satisfying the exclusionary constraint.

Table 8 shows that the coefficient for environmental investment in the OLS estimation is 0.0159 ($p < 0.01$), while the coefficient in the second stage of the 2SLS estimation is 0.0498 ($p < 0.01$), indicating an increase in the coefficient. The F-statistic for the first stage is 394.33, indicating no weak instrumental variable problem. The p-value of the Durbin-Wu-Hausman test is 0.0016, rejecting the null hypothesis that environmental investment is exogenous, thereby confirming the necessity of using the instrumental variables method.

Table 8. Results of the endogeneity test

Variable	OLS	2SLS
ln env invest	0.0159***	0.0498***
	(0.0036)	(0.0116)
size	0.4320***	0.4374***
	(0.0070)	(0.0084)
leverage	0.0987**	0.0768
	(0.0400)	(0.0441)
roa	-0.4709***	-0.4260***
	(0.1090)	(0.1177)
Firm age	-0.0057***	-0.0072***
	(0.0013)	(0.0014)
soe	0.2273***	0.2186***
	(0.0254)	(0.0270)
Year FE	Tes	Yes
Industry FE	Yes	Yes
Province FE	Yes	Yes
N	19,940	17,133
F		394.33
p		0.0016

Note: Standard errors in parentheses are robust; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The 2SLS model uses one-period lagged environmental investment (L ln env invest) as an instrumental variable.

As can be seen, even after accounting for potential endogeneity issues, the positive incentive effect of environmental investment on green technology innovation remains robust. Combined with the baseline regression and a series of robustness tests discussed earlier, the core conclusions of this paper are highly credible.

5. Conclusion

Based on data from A-share listed companies on the Shanghai and Shenzhen stock exchanges from 2010 to 2023, this paper examines the impact of environmental protection investment on corporate green technological innovation. The study finds that environmental protection investment has a significant positive incentive effect, and this conclusion holds even after multiple robustness tests and endogeneity treatments. Mechanism tests indicate that financing constraints are the core transmission channel, while the R&D investment channel is not significant; the role of environmental protection investment lies in improving the corporate financing environment through signalling. Heterogeneity analysis reveals that this effect is more pronounced in non-state-owned enterprises and high-carbon industries. Based on the above findings, this paper proposes the following policy recommendations: incorporate corporate environmental protection investment into the green finance policy framework and introduce an environmental protection investment intensity indicator in the certification of green enterprises; establish special credit lines for green transition in non-state-owned enterprises and provide tax incentives for new environmental protection investments by enterprises in high-carbon industries; simultaneously, strengthen the disclosure of environmental protection investment information to enhance the transparency of green capital expenditures. This study also has certain research limitations. For instance, missing R&D data may lead to sample selection bias; endogeneity issues require further identification using exogenous policy shocks; and the examination of dynamic effects remains insufficient. Future research may deepen the analysis in these areas.

Disclosure statement

The author declares no conflict of interest.

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