

The Influence of Corporate Investment in Environmental Protection on Low-Carbon Technology Innovation: An Analysis of the Mediating Role of Environmental Benefits and the Moderating Role of Market Share

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Abstract: With the promotion of green economies, green and low-carbon development has become a key issue for business growth. This paper conducts a literature review and empirical analysis to examine the impact of environmental protection investments by enterprises on low-carbon technology innovation. It focuses on the mediating role of environmental benefits and the moderating role of market share, as well as their interrelationships and mechanisms of effect. The results indicate that investments in environmental protection significantly promote innovation in low-carbon technologies. Additionally, environmental benefits partially mediate this relationship. In other words, environmental protection investments enhance low-carbon technology innovation by improving environmental benefits. Furthermore, this study introduces an interaction model to assess the moderating effect of market share, revealing that market share significantly influences the impact of environmental protection investments on low-carbon technology innovation. Lastly, the paper analyzes the differences in the performance of environmental protection investments based on ownership type.

Keywords: Environmental protection investment, Low-carbon technology innovation, Environmental benefits, Market share

1. Introduction

Achieving green and low-carbon development relies heavily on low-carbon technological innovation, which serves as a crucial driver of high-quality economic growth. Governments have facilitated this transformation through policy support, tax incentives, and green financing, encouraging businesses to invest in environmental protection and to advance the research, development, and application of green technologies. For example, the Paris Agreement explicitly calls for a reduction in greenhouse gas emissions and promotes the adoption of low-carbon technologies. Additionally, rising public awareness of environmental issues and the growing market demand for green products have prompted companies to increase their investment in environmental protection and technological innovation. To secure a competitive edge in the green economy, many companies are actively pursuing innovation in technology. Therefore, it is essential to examine the relationship between environmental protection investment and low-carbon technology innovation, as well as the mechanisms that underpin this relationship. While existing research has primarily focused on the direct connection between

environmental protection investment and innovation, it often overlooks the deeper internal mechanisms and logical relationships involved. This study aims to analyze the interplay among enterprise environmental protection investment, environmental benefits, market share, and low-carbon technology innovation using a new research framework.

2. Literature review

In recent years, the growing challenges of global climate change and environmental pollution have made low-carbon technology innovation an essential strategy for addressing climate change and promoting sustainable development. It has also become a critical way for enterprises to enhance their market competitiveness and undergo strategic transformation. By adopting low-carbon technologies, companies can optimize their production processes and improve resource efficiency while complying with environmental protection standards. This ultimately reduces costs and boosts competitiveness. Xie and Han noted that green innovation drives the transformation of manufacturing enterprises through various technical routes and models [1]. These transformation models primarily involve technological upgrades, enabling companies to stand out in a competitive market. Furthermore, green technology innovation significantly influences funding costs, default risks, and long-term development strategies of businesses [2]. Overall, while the academic community has largely focused on the outcomes of low-carbon technology innovation, there is a growing interest in the factors that influence this innovation.

Some studies indicate that the driving forces behind green technology innovation often stem from market demand, policy incentives, or corporate strategic choices, all of which play a crucial role in fostering green innovation [3]. Additionally, some researchers have examined the relationship between environmental protection investments and low-carbon technology innovation. For example, certain scholars argue that companies with higher expenditures on environmental protection will likely demonstrate greater levels of green innovation in the future [4]. However, the direct influence of environmental protection investments as a motivating force for advancing low-carbon technology innovation has not been conclusively proven. Studies indicate that the implementation of pollution taxes significantly boosts R&D spending by high-polluting companies, highlighting the role of environmental protection investments in promoting technological innovation [5]. Therefore, it is essential to introduce environmental protection investment as an independent variable in this study to further investigate its relationship with low-carbon technology innovation.

Environmental protection investments may enhance production processes and optimize resource utilization, thereby improving the efficiency and quality of technological innovation. Moreover, environmental pressures can have varying effects on green innovation [6], indicating that the impact of environmental protection investments may differ depending on external conditions. In this study, environmental benefits serve as a mediating variable. This concept encompasses not only the achievements of enterprises in reducing pollution and carbon emissions but also the broader advantages related to energy conservation, resource recycling, and other aspects. Research shows that strengthening environmental protection possesses both social and economic rationality, particularly in front-end governance, where environmental and economic benefits are significant [7]. Consequently, introducing environmental benefits as a mediating variable allows for a more comprehensive understanding of how environmental protection investments can promote low-carbon technology innovation through enhanced environmental outcomes.

In summary, low-carbon technology innovation is an important force promoting sustainable development, in which environmental investment, environmental benefits, and market share play a crucial role. Although existing research has extensively explored the influencing factors of low-carbon technology innovation, the direct impact of environmental investment on low-carbon technology innovation, as well as the mediating effect of environmental benefits and the moderating

effect of market share, have not received sufficient attention. This paper aims to systematically analyze the relationship among environmental protection investment, low-carbon technology innovation, environmental benefit and market share by constructing a theoretical framework of four factors.

3. Research hypothesis

Earlier studies primarily focused on external environmental pressures and technological spillover effects [8], suggesting that government environmental regulations stimulate corporate innovation through coercive mechanisms. However, these studies often neglect the fact that companies can actively choose strategic inputs, such as environmental protection investments, to meet external environmental requirements and achieve optimal resource allocation. Recently, scholars have turned their attention to the "green resource-based view" [9], which emphasizes the significance of internal resource investments for sustainable technological innovation, including R&D funding and the acquisition of environmental protection equipment [10]. Despite this focus, the mechanisms underlying environmental protection investments remain unclear. On one hand, such investments help companies effectively reduce environmental burdens in their production and operations and promote ongoing advancements in low-carbon technology by enabling them to concentrate resources on the research, development, and application of environmental protection technologies. On the other hand, the resource restructuring aspect of environmental protection investments aids in optimizing technological pathways and overcoming barriers to low-carbon technology innovation. Furthermore, Friedman's agency theory once criticized the "unproductive" nature of green investments, while Freeman's stakeholder theory illustrates that these investments can lower technology conversion costs by enhancing supply chain collaboration (such as through green supplier certification). Hence, corporate investments in environmental protection can overcome systemic barriers to low-carbon technology innovation through targeted resource restructuring and the activation of external networks, thereby positively contributing to such innovation:

H1: Enterprise environmental protection investment has a positive effect on enterprise low-carbon technology innovation

In academia, research on corporate environmental investment initially concentrated on its effects on economic benefits for corporations. This perspective explored how investments in environmental protection could enhance financial performance by improving production efficiency, reducing costs, or securing policy subsidies [11]. However, as environmental issues have become more pressing, an increasing number of researchers have shifted their focus to the environmental benefits of corporate environmental investment, particularly how to enhance ecological value through optimized resource allocation. The resource orchestration theory proposed by Sirmon in 2011 suggests that environmental investment can achieve economies of scale in environmental benefits through the integration and leveraging of resources, such as obtaining policy subsidies by disclosing environmental data. Empirical studies further indicate that the "structural heterogeneity" of environmental protection investments leads to variations in environmental benefits. Specifically, end-of-pipe governance investments might result in only marginal emissions reductions, while preventive investments can significantly enhance ecological efficiency [12]. Additionally, the multi-stage nature of environmental protection investments allows for coverage of these complex objectives. Therefore, corporate investments in environmental protection can positively influence outcomes through structural optimization and systematic improvements in environmental benefits. Based on this understanding, this study proposes:

H2: Enterprise environmental protection investment has a positive effect on environmental benefits

It suggests examining the transmission mechanism of environmental benefits and low-carbon technology innovation within the framework of "dual circulation." On one hand, environmental benefits can lower the costs associated with technological trial and error. For example, the recycling of waste can provide essential experimental materials for developing low-carbon technologies [13]. On the other hand, companies that achieve high environmental benefits are more likely to secure government green purchase orders, which guarantee market demand for their technological innovations [14]. However, much of the existing literature treats environmental benefits as a mere by-product of technological innovation, as suggested by the "Porter hypothesis," overlooking their proactive enabling role [15]. According to the dynamic capability theory proposed by Teece in 2007, the accumulation of environmental benefits can enhance a company's "green absorption capacity." For instance, pollution monitoring data can help identify opportunities for technological improvements. Consequently, investments in environmental protection could become a primary driver of low-carbon technology innovation through the positive influence of environmental benefits.

When analyzing the efficiency of technology conversion in corporate environmental protection practices, scholars generally agree that external situational factors, particularly the market environment, significantly influence this efficiency. Some researchers have observed that market share not only indicates a company's control over the market but also reflects its ability to manage external risks, especially regarding environmental protection investments [16]. Specifically, companies with a high market share can reduce the costs of environmental protection efforts through economies of scale and leverage their market power to turn environmental benefits into technological advantages [17]. In contrast, companies with low market share face greater competitive pressures, which may limit their environmental protection efforts to merely meeting compliance requirements, making it challenging for them to achieve technological breakthroughs [18]. Thus, the advantages of market share also manifest in environmental protection investments, further supporting the transfer of environmental benefits into low-carbon technology innovation. Based on this understanding, this study proposes:

H3: Environmental protection investment affects enterprise low-carbon technology innovation through the mediating path of environmental benefits

H4: Market share can mediate the impact of environmental investment on corporate low-carbon technology innovation through environmental benefits.

4. Research design

4.1. Variable definition and measurement

(1) Dependent variable

According to existing literature, low-carbon technology innovation is usually carried out by the number of patents, and the measurement criteria for low-carbon technology innovation include green invention patents involving innovation fields such as energy conservation and emission reduction, low-carbon environmental protection, and green utility model patents involving general application fields in life. In many previous literatures, the sum of the number of green invention patents and green utility model patents independently obtained by enterprises in the current year is generally used as the measurement standard for low-carbon technology innovation [19]. This paper also follows this approach and takes the logarithm to eliminate the impact of scale differences, thereby effectively reflecting the innovative achievements of enterprises in the field of low-carbon technology.

(2) Independent variable

Environmental protection investment is an economic activity undertaken by a company to comply with environmental laws and regulations, reduce environmental pollution, or promote green development. In this paper, the measurement standard for corporate environmental protection

investment is the total annual environmental expenditure of the company, and the logarithm of the environmental protection investment amount is used to measure the company's environmental investment to eliminate the impact of differences in corporate size. This indicator more directly reflects the intensity of a company's investment in environmental protection, and its use is also widely seen in empirical research related to corporate environmental behavior [20].

(3) Mediating variable

Based on the measurement of environmental benefits in a large number of previous literature [21], combined with the news released by Beijing Municipal Ecology and Environment Bureau and other government agencies, this paper chooses pollutant emission reduction as the measure of environmental benefits, mainly including atmospheric pollutants such as carbon dioxide, nitrogen oxides, and sulfur oxides. The specific calculation method is the amount of pollution reduced by the enterprise through environmental protection measures in a certain year, and takes its logarithm as the proxy variable of environmental benefits, which can directly reflect the improvement effect of the enterprise's environmental protection measures on the environment. The higher the pollutant emission reduction, the better the environmental benefit.

(4) Moderating variable

As a moderating variable, market share reflects the competitive position of an enterprise in the market. The size of the market share may affect the decision-making of enterprises in environmental protection investment and the motivation and effectiveness of their low-carbon technology innovation. In this paper, the measurement standard of market share adopts the market share of the annual sales revenue of the enterprise in the industry, so as to better reflect the competitiveness of the enterprise in the industry. Through this standard, the response strategy and innovation potential of enterprises in the face of environmental protection policy pressure can be effectively evaluated, and it is also helpful to analyze the relationship between their decision-making mode of environmental protection investment and market performance.

(5) Control variable

Since enterprise characteristics and management structure have a potential impact on green technology innovation, this paper selects board size, board independence, and capital intensity as control variables.

Table 1: Definition of variables

Types of Variables	Variables	Definition of Variables	Measurement
Dependent Variable (Y)	Tech	Low-Carbon Technology Innovation	Log of the Number of Green Patents
Independent Variable (X)	Inv	Environmental Investment	Log of Environmental Investment
Mediating Variable (M)	Benefit	Environmental Benefit	Log of Pollutant Emission Reduction
Moderating Variable (W)	Mkt	Market Share	Ratio of Operating Income of a Single Company to the Income of the Industry
	B	Board Size	Log of the Number of Board Members
	Ind	Board Independence	The ratio of the Number of Independent Directors to the Size of the Directors
Control Variable (C)	Fix	Capital Intensity	The ratio of Total Assets to Operating Income

4.2. Sample selection and data sources

Based on data availability, this study selected Shanghai and Shenzhen A-share listed companies in 2023 as research samples. In order to ensure the accuracy and validity of the data, this study excluded

all ST, *ST, and listed companies with incomplete information, and performed tailing processing on all continuous data at the 1% and 99% percentiles to avoid the influence of extreme values. After screening, 1113 valid annual observations were finally obtained. In terms of data sources, green patent data mainly comes from the CNRDS database, and the rest of the data comes from the CSMAR database.

4.3. Model construction

In order to test the hypothesis H1 H2 and H3, this paper introduces the mediation effect model and conducts a stepwise regression analysis of the impact of environmental protection investment on low-carbon technology innovation through environmental benefits. The settings are as follows:

$$\text{Tech}_{i,t} = \alpha_0 + \alpha_1 \text{Inv}_{i,t} + \alpha_i \text{Controls}_{i,t} + \sum \text{Year} + \varepsilon_{i,t} \quad (1)$$

$$\text{Benefit}_{i,t} = \beta_0 + \beta_1 \text{Inv}_{i,t} + \beta_i \text{Controls}_{i,t} + \sum \text{Year} + \varepsilon_{i,t} \quad (2)$$

$$\text{Tech}_{i,t} = \gamma_0 + \gamma_1 \text{Inv}_{i,t} + \gamma_2 \text{Benefit}_{i,t} + \gamma_i \text{Controls}_{i,t} + \sum \text{Year} + \varepsilon_{i,t} \quad (3)$$

i and t represent individual enterprises and years respectively, α_1 represents the total effect of environmental protection investment on low-carbon technology innovation, γ_1 indicates the direct effect of environmental protection investment on low-carbon technology innovation, $\beta_1 \times \gamma_2$ represents the mediating effect of environmental benefits, $\sum \text{Year}$ represents the year fixed effect, and $\varepsilon_{i,t}$ is a random disturbance term.

To test hypothesis H4, the moderating effect of market share on the role of environmental protection investment in low-carbon technology innovation is tested by adding the cross-product of the independent variable and the moderating variable. The specific settings are as follows:

$$\text{Tech}_{i,t} = \sigma_0 + \sigma_1 \text{Inv}_{i,t} + \sigma_2 \text{Mkt}_{i,t} + \sigma_3 \text{Inv}_{i,t} \times \text{Mkt}_{i,t} + \sigma_i \text{Controls}_{i,t} + \sum \text{Year} + \varepsilon_{i,t} \quad (4)$$

The model measures the moderating effect with the coefficient of the interaction term ($\text{Inv}_{i,t} \times \text{Mkt}_{i,t}$), σ_3 reflecting the moderating effect of market share on the impact of environmental protection investment on low-carbon technology innovation.

5. Analysis of empirical results

5.1. Descriptive statistics

The descriptive statistics of the main variables in this study are shown in Table 2. First of all, the sample includes data on environmental protection investment, low-carbon technology innovation, and related variables of several companies.

Table 2: Descriptive statistics

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
Inv (log)	1,113	7.340	2.224	2.389	12.75
Tech (log)	1,113	0.510	0.850	0	4.200
Benefit (log)	1,113	10.03	4.732	0.470	22.04
Mkt (%)	1,113	2.792	6.826	0.0110	45.04
B (log)	1,113	2.249	0.178	1.792	2.773
Ind (%)	1,113	37.85	5.603	33.33	57.14
Fix (%)	1,113	2.889	4.533	0.326	35.46

According to the descriptive statistics of the sample, we obtained the mean, standard deviation, minimum, and maximum values of each variable. The mean of environmental investment (Inv) is 7.340, the standard deviation is 2.224, and the maximum value can reach 12.75. This result shows that different enterprises are subject to different environmental regulations and environmental responsibilities, and their investment in environmental protection has certain differences. The mean of low-carbon technology innovation (Tech) is 0.510 and the standard deviation is 0.850, indicating that although there are differences in the enthusiasm of Chinese enterprises for low-carbon technology innovation, and the minimum value is 0, the overall willingness is high. The mean of environmental benefit (Benefit) is 10.03 and the standard deviation is 4.732, which also shows the volatility of environmental benefits.

Through factor analysis, the distribution of each variable is relatively normal, and there is no obvious skewness or extreme value. In particular, for the two main continuous variables, environmental protection investment (Table 3) and environmental benefits (Table 4), the data showed a relatively balanced distribution, indicating that the sample selection met the requirements of the research subjects and did not deviate significantly from the normal distribution. The data reliability was high, which could meet the premise assumptions of regression analysis.

Table 3: Factor analysis of the independent variable

Inv_ average	Freq.	Percent	Cum.
0	586	52.65	52.65
1	527	47.35	100.00
Total	1113	100.00	

Table 4: Factor analysis of the mediating variable

Benefit_ average	Freq.	Percent	Cum.
0	497	44.65	44.65
1	616	55.35	100.00
Total	1113	100.00	

5.2. Mediation effect

The results are shown in Table 5 Specifically, environmental benefits are used as a mediating variable to examine how environmental protection investment affects the realization of low-carbon technology innovation through environmental benefits.

Table 5: Mediator effect results

	(1) t1 Tech	(2) t2 Benefit	(3) t3 Tech
VARIABLES			
Benefit			0.0116** (0.00554)
Inv	0.0441*** (0.0116)	0.602*** (0.0628)	0.0371*** (0.0121)
B	0.495*** (0.171)	1.588* (0.928)	0.477*** (0.171)
Ind	0.0115** (0.00532)	0.0263 (0.0288)	0.0112** (0.00531)

Table 5: (continued)

Fix	-0.0167*** (0.00573)	0.0343 (0.0310)	-0.0171*** (0.00573)
Constant	-1.316*** (0.510)	0.949 (2.760)	-1.327*** (0.509)
Observations	1,113	1,113	1,113
R-squared	0.033	0.087	0.036

Standard errors in parentheses:***p<0.01, **p<0.05, *p<0.1

First, we verified the relationship between environmental protection investment (Inv) and low-carbon technology innovation (Tech) through regression analysis. The regression results show that environmental protection investment has a significant positive impact on low-carbon technology innovation, with a regression coefficient of 0.0441 ($p < 0.01$). This result shows that environmental protection investment can promote the innovation of low-carbon technology, verifying the H1 hypothesis that there is a significant positive relationship between environmental protection investment and low-carbon technology innovation.

Next, we examined the relationship between environmental investment (Inv) and environmental benefit (Benefit). The regression analysis results show that environmental investment also has a significant positive impact on environmental benefits, with a regression coefficient of 0.602 ($p < 0.01$), indicating that environmental investment can promote sustainable development by improving environmental benefits.

Finally, we analyzed the joint effect between environmental protection investment (Inv), environmental benefits (Benefit), and low-carbon technology innovation (Tech). The results of the mediation effect analysis showed that environmental benefits played a significant mediating role between environmental protection investment and low-carbon technology innovation, with a regression coefficient of 0.0116 ($p < 0.05$). This result shows that environmental protection investment not only directly affects low-carbon technology innovation, but also plays an indirect role through the mediating variable of environmental benefit, and there is a partial mediation effect.

In order to enhance the stability and reliability of the conclusions on the mediating effect of environmental benefit, this paper combined the empirical results of the causal stepwise regression model and used the Bootstrap method to conduct a 500-time sampling test on the research sample to conduct a robustness test of the mediating effect, thereby verifying the mediating effect (as shown in Table 6).

Table 6: Bootstrap results

	Observed coefficient	Bootstrap std. err.	z	P> z	Normal-based [95% conf. interval]	
Indirect effect	0.0069956	0.0034925	2.00	0.045	0.0001505	0.0138408
Direct effect	0.0370981	0.0137567	2.70	0.007	0.0101356	0.0640606

According to Table 6, at the 95% confidence level, environmental benefits have a partial mediating effect on low-carbon technology innovation, and the mediating effect accounts for about 16%. The Bootstrap test results above are consistent with the previous empirical research results. Therefore, hypotheses H1, H2, and H3 are all established.

5.3. Moderating effect

Based on the above empirical analysis, in order to explore the moderating effect of market share (Mkt), we introduced the interaction term ($Inv \times Mkt$) between environmental investment and market share as an independent variable. When constructing the interaction term, we multiplied Inv and Mkt to obtain the interaction term variable. The addition of this interaction term is to test whether market share plays a moderating role between environmental protection investment and low-carbon technology innovation. The regression analysis results in Table 7 show that when the regression coefficient of $Inv \times Mkt$ is 0.005 ($p < 0.01$), market share significantly regulates the relationship between environmental protection investment and low-carbon technology innovation.

Table 7: Regulatory effect results

VARIABLES	(1) a1 Tech	(2) a2 Tech
Inv	0.044*** (3.80)	0.036*** (2.97)
Mkt		0.001 (0.18)
Interact		0.005*** (3.23)
B	0.495*** (2.89)	0.432** (2.50)
Ind	0.012** (2.17)	0.009 (1.59)
Fix	-0.017*** (-2.91)	-0.016*** (-2.77)
Constant	-1.316*** (-2.58)	-1.022** (-1.98)
Observations	1,113	1,113
R-squared	0.033	0.046
Yearfix	YES	YES
Codefix	YES	YES

t-statistics in parentheses:*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

In addition, in order to further verify the existence of heterogeneity, we divided the ownership of enterprises and conducted heterogeneity analysis on state-owned enterprises (denoted as 0) and non-state-owned enterprises (denoted as 1). According to the regression analysis results (Table 8), we found that in state-owned enterprises, environmental protection investment has a more obvious effect on low-carbon technology innovation, with a regression coefficient of 0.058 ($p < 0.01$), indicating that the effect of environmental protection investment in state-owned enterprises is greater, so that the subsequent market share plays a more prominent role in promoting low-carbon technology innovation.

Table 8: Analysis of heterogeneity

	(1) Tech	(2) Tech
Inv	0.058 ** (3.2568)	0.030 (1.4474)
B	0.769 * (2.5043)	0.004 (0.0171)
Ind	0.014 (1.8209)	0.003 (0.3477)
Fix	-0.015 *** (-3.5892)	-0.023 *** (-3.6098)
_cons	-2.154 * (-2.3778)	0.178 (0.2202)
N	507	566
r2_a	0.047	0.009

t statistics in parentheses: * p < 0.05, ** p < 0.01, *** p < 0.001

Therefore, in summary, the moderating effect analysis shows that market share plays an important moderating role in the relationship between environmental protection investment and low-carbon technology innovation, and this role significantly varies among different types of enterprises.

6. Conclusions

Based on the findings of this study: 1. There is a significant positive relationship between investment in environmental protection and innovation in low-carbon technology, particularly within state-owned enterprises. In the context of increasing environmental protection regulations, companies are responding to external pressures and market demand changes through low-carbon technology innovation. 2. Environmental benefits partially mediate the relationship between environmental protection investment and low-carbon technology innovation. By enhancing environmental conditions, such investments allow companies to accumulate valuable data and experience, thereby improving their ability to identify opportunities for technological advancement. 3. Market share significantly moderates the impact of environmental protection investment on low-carbon technology innovation. Enterprises with larger market shares are generally more motivated to maintain their leadership position and competitiveness in light of environmental protection requirements.

Based on the above conclusions, this paper offers the following recommendations: 1. Strengthen the connection between environmental protection investment and technological innovation. Enterprises should establish an innovation management system to facilitate the effective allocation of funds for environmental protection investment and technological research and development. 2. Optimize the evaluation and management system for environmental benefits. Companies should view the management of environmental benefits from protection investments as a crucial driver for low-carbon technology innovation. 3. Expand market share and boost innovation momentum. Companies should work to increase their market share and competitiveness by refining their product offerings and enhancing technological content. This approach will further propel the role of environmental protection investment in facilitating low-carbon technology innovation.

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