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Emissions Trading, Green Innovation, and Sustainable Finance: Evidence from China's SO_2 Pilot on Firms' Cost of Equity

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Abstract

Emissions trading systems have been widely adopted to address environmental externalities, yet their capital market consequences remain underexplored. Using China's 2007 pilot SO_2 emissions trading policy as a quasi-natural experiment, this study examines the effect of market-based environmental regulation on firms' cost of equity capital based on a sample of A-share listed firms from 2003 to 2023. The results from a two-way fixed-effects difference-in-differences model show that the pilot SO_2 emissions trading policy significantly reduces firms' cost of equity capital and that this effect gradually strengthens over time after policy implementation. Further analysis indicates that the pilot policy significantly enhances firms' green innovation, ESG disclosure, and institutional ownership. Moreover, the cost-reducing effect is more pronounced among firms with stronger green innovation capability, better ESG performance, and higher levels of institutional investor participation, providing supportive evidence for three potential channels: green innovation, an improved information environment, and an optimized investor structure. Heterogeneity analysis further shows that the policy effect is more pronounced for non-state-owned firms, firms facing stronger financing constraints, and firms located in regions with stricter environmental enforcement. Overall, this study demonstrates that market-based environmental regulation not only serves environmental governance objectives but also improves firms' financing conditions by influencing risk pricing in capital markets. These findings provide empirical evidence on the capital market consequences of emissions trading systems and offer policy implications for the further refinement of such institutional arrangements.

Keywords: SO_2 emissions trading; cost of equity capital; green innovation; ESG disclosure; institutional ownership

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Academic Editor: Camelia Delcea

Received: 28 January 2026
Revised: 28 March 2026
Accepted: 2 April 2026
Published: 5 April 2026

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1. Introduction

The swift advancement of globalization signifies that the economic prosperity of any nation constitutes a worldwide concern, as do environmental issues. Achieving a balance between environmental sustainability and economic progress poses a significant challenge for global policymakers and economists. The Environmental Performance Index (EPI) report published by Yale University indicates that numerous countries face challenges in environmental conservation. In the Environmental Performance Index, China is positioned

156th out of 180 countries overall and performs particularly poorly in air quality indicators (Yale Center for Environmental Law & Policy. (n.d.). Environmental Performance Index (EPI). Retrieved 8 August 2025, from https://epi.yale.edu). Throughout the years of reform and opening up, the Chinese economy advanced significantly but at an accelerated rate and with considerable environmental and ecological costs. China is the foremost global consumer of energy and the largest emitter of greenhouse gases [1], encountering challenges in attaining sustainable growth due to resource depletion and pollution. These tensions make China an informative setting for studying whether environmental policy can improve environmental outcomes while also affecting capital market risk pricing.

In response to resource depletion and environmental degradation, China has prioritized ecological civilization as a national goal and implemented various policies, such as carbon markets, stringent emission regulations, and the promotion of renewable energy. These initiatives have enhanced environmental quality and bolstered China's position in global climate governance [2–5]. One of the key policy tools introduced in 2007 was the SO_2 emissions trading system, designed to reduce sulfur dioxide emissions from major polluting industries such as power generation, chemicals, and metallurgy. In this pilot system, firms in designated regions receive or purchase emission allowances under total emission control and can trade allowances in the market, thereby putting an explicit price on SO_2 emissions. The SO_2 ETS represents China's first step into market-driven environmental regulation, aiming to internalize the environmental costs associated with industrial emissions [6–9]. Because the policy was implemented as a pilot across selected regions, it also provides a quasi-natural experimental setting to identify causal effects on corporate financial outcomes.

China's emissions trading system has yielded notable outcomes, seen particularly in the substantial decrease in sulfur dioxide and carbon dioxide emissions. This illustrates that market processes are essential in compelling firms to decrease emissions [10–12]. More broadly, market-based environmental regulation may alter firms' risk profiles and information environments, which are directly relevant to the cost of equity capital. China's environmental governance experience therefore holds policy relevance for the global community by illustrating potential synergies between economic development and ecological preservation through institutional innovation. In particular, understanding how an early-stage, local pollutant SO_2 ETS affects equity risk pricing can inform countries considering market-based approaches to conventional air pollution control.

Environmental regulation has garnered significant academic attention, as it influences both enterprises' environmental performance and their financial behavior and investment decisions. Environmental policy interventions significantly enhance firms' performance in environmental, social, and governance dimensions [13]. Environmental regulatory frameworks, such as the River Chief System, significantly enhance enterprises' performance in environmental, social, and governance aspects. These policies can effectively assist organizations in achieving more sustainable actions [14,15]. The research findings robustly support Porter's hypothesis, which illustrates that robust and comprehensive environmental restrictions might induce a unique compensating effect, thus enhancing enterprises' competitiveness. Nevertheless, existing evidence is still limited on whether market-based environmental policy tools—especially early-stage pilots in emerging economies—systematically affect firms' cost of equity capital, a core measure of equity financing costs and a key input into investment and valuation. Moreover, prior studies often examine either environmental outcomes or corporate performance, but less is known about the channels through which ETS policies may influence capital market pricing.

This study evaluates policy's influence on firms' capital investment costs by treating China's 2007 pilot sulfur dioxide (SO_2) pollution trading scheme as a simulated natural experiment. By utilizing a difference-in-differences (DID) methodology, the research explores whether and how market-based environmental regulations influence firms' cost of equity capital through three distinct but complementary channels: green technological innovation, environmental information disclosure, and institutional investor ownership. Specifically, we test the main relationship between the SO_2 ETS and firms' cost of equity capital and then examine three mechanisms through green innovation, ESG and environmental disclosure, and institutional ownership. This study makes four contributions to the literature and policy debate: First, it provides systematic evidence on how an early-stage market-based environmental regulation, the SO_2 ETS pilot, affects firms' cost of equity capital in an emerging economy. Second, it clarifies the channels through which the policy influences equity risk pricing by examining green innovation, ESG and environmental disclosure, and institutional ownership as mechanism pathways. Third, it documents heterogeneity in the policy effect across firm ownership and financing conditions and across regions with different enforcement intensity, offering implications for more targeted ETS design and implementation. Finally, by connecting market-based pollution control to equity financing costs, the study contributes to the broader conversation on sustainable finance and ESG-related capital allocation.

2. Theoretical Analysis and Research Hypotheses

2.1. Green Innovation Effect

An emissions trading system is an environmental regulatory tool that uses market mechanisms to control emissions of pollutants. Whether targeting regional pollutants such as sulfur dioxide or global pollutants such as carbon dioxide, it conveys price signals through quota restrictions and trading. This influences corporate resource allocation, technology selection and investment strategies. These impacts evidently translate into firms' green innovation performance [16].

However, existing research on the impact of emissions trading systems on corporate innovation remains contentious. Some scholars argue that such systems provide limited incentives for innovation. For example, Rogge et al. [17] found that the institutional framework of the EU Emissions Trading Scheme lacked intrinsic mechanisms to incentivize corporate technological innovation sustainably, based on a study of German energy companies. However, other scholars emphasize their capacity to unlock innovation potential [18]. Under certain conditions, environmental policies and tools such as emissions trading can create synergies between environmental outcomes and corporate innovation performance [19,20].

In recent years, the environmental and economic synergies of China's emissions trading policy have received considerable attention. Long-term evidence confirms that this policy reduces pollution emissions while improving corporate economic performance, primarily through enhanced green innovation outcomes [21]. Specifically, drawing on the Porter hypothesis, the SO_2 emissions trading system internalizes the external costs of air pollution into firms' decision-making through a pricing mechanism and raises the marginal cost of emissions. This, in turn, compels firms to increase investment in green technology research and development, improve energy efficiency, and reduce environmental compliance costs and innovation uncertainty through technological progress.

In summary, according to environmental risk transmission theory, as enterprises enhance their green technological innovation capabilities over the long term, their environmental compliance risks and policy uncertainties decrease accordingly. Consequently, capital markets improve their assessment of enterprises' long-term risks, thereby optimiz-

ing their equity financing environment. Based on the above analysis, this paper proposes the following hypothesis:

Hypothesis 1: *SO_2 emissions trading enhances firms' green innovation, thereby reducing their cost of equity capital.*

2.2. ESG Disclosure Effect

As a core element in corporate financing decisions, capital structure optimization and investment activities, equity capital cost has long been a focal point in academic research. In recent years, scholars have conducted in-depth studies of equity capital cost from the perspective of information disclosure, drawing on multidimensional theoretical frameworks such as information asymmetry theory and signaling theory.

Based on information asymmetry theory, Chen and Zhang [22] claim that corporate social responsibility (CSR) disclosure lowers financing costs by mitigating long-term operational risks and reducing the risk premium demanded by investors. Their findings show that companies with a strong environmental performance have lower equity capital costs. Furthermore, Shan and Wang [23] demonstrate that the level of CSR disclosure negatively correlates with equity capital costs and that this relationship is more pronounced in highly competitive industries. This highlights the differential impact of information transparency on capital markets. Based on signaling theory, Long et al. [24] discovered a lagged U-shaped relationship between corporate capital costs and carbon information disclosure. This indicates that the impact of comprehensive disclosure on capital expenditure exhibits temporal lags. Companies must therefore continuously release effective signals to influence capital markets.

Regarding environmental information disclosure, existing research generally agrees that robust disclosure significantly reduces corporate capital expenditure [25]. For example, Xu et al. [26] observe that disclosing carbon emissions substantially reduces firms' implied capital costs, due to increased investor information resulting from greater environmental transparency, thereby enhancing stock liquidity.

The implementation of an emissions trading system can enhance corporate environmental transparency in three ways: First, mandatory reporting and verification systems require enterprises to publicly disclose emissions data and maintain comprehensive environmental information ledgers. Secondly, market-driven incentives encourage enterprises to proactively disclose information because detailed disclosure reduces transaction costs and increases the value of emission rights assets. Thirdly, third-party verification mechanisms introduce professional institutions for auditing data, preventing environmental data falsification through multi-stakeholder oversight, and forming a closed-loop system for supervising the disclosure of information.

In summary, based on information asymmetry theory and signaling theory, improved environmental information disclosure resulting from the implementation of an emissions trading system is expected to enhance corporate credibility, reduce carbon risk and consequently lower the demand for risk compensation in capital markets. Based on this, the following research hypothesis is proposed:

Hypothesis 2: *SO_2 emissions trading enhances firms' ESG disclosure, thereby reducing their cost of equity capital.*

2.3. Institutional Ownership Effect

The impact of the emissions trading system on corporate equity capital costs is primarily mediated through institutional investor holdings. These investors have specialized information processing capabilities and a long-term investment perspective, which makes

them more sensitive to corporate environmental risk characteristics and sustainable operational capacity. By promoting green technological innovation and enhancing environmental transparency, the emissions trading system signals reduced environmental risk and improved sustainability to capital markets. This influences institutional investors' investment decisions. At the same time, institutional investors' participation and increased shareholding further alleviates information asymmetry between enterprises and external investors. Through the implementation of oversight and governance measures, institutional investors improve corporate environmental management standards and promote long-term value creation, thereby influencing investors' assessments of corporate risk premiums.

As a market-based environmental regulatory tool, the pilot sulfur dioxide emissions trading scheme alters production constraints and information transparency by internalizing the external costs of pollution. Emissions trading increases firms' environmental compliance costs, enhances the visibility of environmental performance and makes firms more vulnerable to environmental risks and regulatory oversight. Against this backdrop, institutional investors with a long-term investment perspective and professional information processing capabilities are more likely to increase their holdings in regulated firms. They mitigate environmental uncertainty through research, oversight and governance measures.

Firstly, public institutional investors leverage governance synergies and information-sharing mechanisms to improve corporate environmental governance and operational transparency, thereby generating 'supervision economies of scale' [27]. Secondly, increased institutional ownership curbs management opportunism through 'exit threats' and governance participation, thereby mitigating information asymmetry and enhancing disclosure quality [28]. Furthermore, studies indicate that increased institutional ownership reduces investor uncertainty regarding future corporate cash flows by strengthening analyst coverage and improving environmental and carbon disclosure [29].

In summary, we anticipate that the emissions trading system will signal reduced environmental risks and enhanced sustainability to capital markets by promoting green technological innovation and increasing environmental transparency, thereby attracting institutional investor participation. Through institutional investor oversight and governance measures, improvements in corporate environmental management and long-term value creation help to reduce market risk premiums on firms, thereby lowering their capital costs.

Based on this, this paper proposes the following research hypothesis:

Hypothesis 3: *SO_2 emissions trading increases institutional ownership, thereby reducing firms' cost of equity capital.*

Figure 1 presents the theoretical framework for how SO_2 emissions trading affects firms' cost of equity capital. Building on the foregoing theoretical analysis, the empirical section adopts a two-step approach to test the proposed mechanism hypotheses. First, it examines whether SO_2 emissions trading significantly affects green innovation, ESG disclosure, and institutional ownership. Second, it investigates whether these mechanism variables strengthen the effect of SO_2 emissions trading on firms' cost of equity capital.

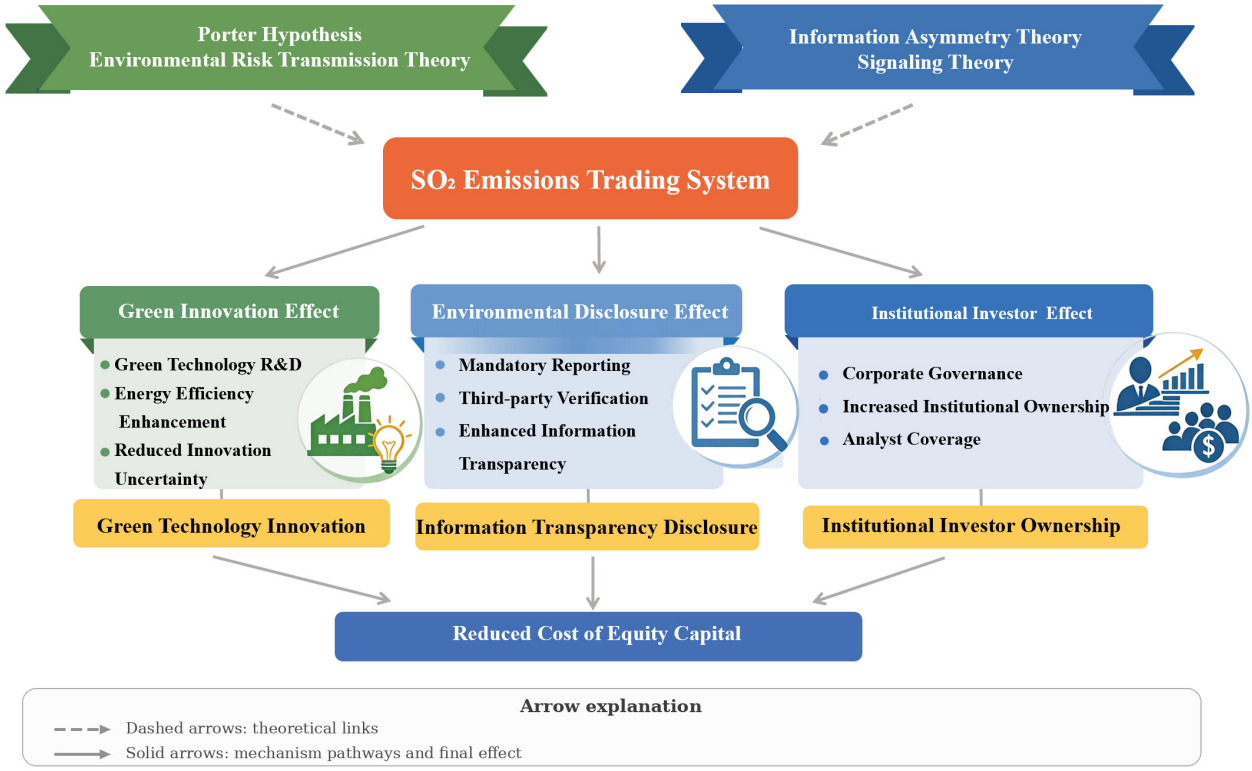

Figure 1. Overall research framework and empirical design.

3. Research Design

3.1. Sample Data and Variable Design

This study examines A-share listed firms operating in sulfur dioxide (SO_2)-intensive industries on the Shanghai and Shenzhen Stock Exchanges over the period 2003–2023. The sample selection follows a systematic screening procedure. According to the Eleventh Five-Year Plan for National Acid Rain and Sulfur Dioxide Pollution Prevention and Control (Huanfa [2008] No. 1) issued by the State Environmental Protection Administration, industries subject to SO_2 emission regulation include power generation, chemicals, petrochemicals, steel, non-ferrous metals, pharmaceuticals, paper, metallurgy, cement, and glass. Companies are classified in accordance with the Shanghai and Shenzhen Stock Exchanges' industry categorization guidelines.

To ensure data quality, we exclude firms designated as ST or *ST due to consecutive losses, firms listed after 2003, and firms that were delisted during the sample period. We also remove firm-year observations with missing values for key variables required to compute the implied cost of equity capital. All continuous variables are winsorized at the first and ninety ninth percentiles to mitigate the influence of outliers. The final sample consists of 497 listed firms, of which 195 are located in provinces participating in the SO_2 emissions trading system pilot program and 302 are located in non-pilot provinces. Firm-level financial, governance, stock price, and analyst forecast data are obtained from CSMAR and supplemented by RESSET and CNRDS, the Chinese National Research Data Service Platform. The detailed definitions and measurement methods of all variables are presented in Table 1.

(1) The SO_2 emissions trading pilot policy

This study constructs the difference-in-differences treatment variable based on policy shocks at the province-year level. The treatment group indicator, Treat, equals 1 if a firm is registered in a pilot province for SO_2 emissions trading and 0 otherwise. Given that the pilot policy was gradually launched around 2007 and that the institutional arrange-

ments and implementation scope became more clearly defined after 2008, the policy time indicator, Post, is defined as 1 for 2008 and thereafter, and 0 for 2007 and earlier. The key explanatory variable is Post × Treat, which captures the institutional shock faced by firms in pilot provinces following policy implementation. To mitigate identification ambiguity arising from the policy transition period, the robustness tests further exclude observations from 2007.

Table 1. Definition and measurement of variables.

Variable Type	Variable Name	Variable	Definition
Dependent variable	*COE*	Cost of equity capital	Implied cost of equity based on PEG model (Easton, 2004) [30]
Independent variable	*Post*	Time dummy variable	Dummy variable equal to 1 for year t greater than or equal to 2008, 0 otherwise
	Treat	Province dummy variable	Dummy variable equal to 1 if firm registered in one of 11 pilot provinces, 0 otherwise
	Post × *Treat*	Policy shock variable	It captures the institutional shock faced by firms in pilot provinces after policy implementation
Mechanism variable	*Patent*	Green innovation	Natural logarithm of one plus the number of green patent applications filed by the firm in the current year
	ESG	ESG disclosure	Firm-year Huazheng ESG rating converted into a numerical and standardized measure
	InstOwn	Institutional ownership	Proportion of shares held by institutional investors at year-end to total shares outstanding
Control Variable	*Size*	Firm size	Natural logarithm of total assets
	Lev	Gearing ratio	Ratio of total liabilities to total assets
	Growth	Revenue growth	Annual growth rate of operating income
	ROE	Profitability	Return on equity
	TAT	Efficiency	Total asset turnover
	BM	Book-to-market ratio	Book-to-market ratio of equity
	Separation	Ownership–control separation	Degree of separation between control rights and ownership
	Top1	Largest shareholder	Shareholding ratio of the largest shareholder
	Top10	Top ten shareholders	Shareholding ratio of the top ten shareholders

(2) Firms' cost of equity capital

Firms' cost of equity capital is measured by the implied cost of equity capital (ICC). Compared with ex-post estimation methods based on historical returns or asset pricing models, the implied cost of equity capital is inferred from stock prices and expected future earnings and thus more directly captures capital market expectations regarding firms' future risk and growth prospects. It is therefore particularly suitable for examining the impact of environmental regulation on firms' equity financing costs. Specifically, this study employs the PEG model proposed by Easton [30] to estimate the cost of equity capital. The formula is as follows:

$$COE_{it} = \sqrt{\frac{EPS_{i,t+2} - EPS_{i,t+1}}{P_{it}}} \quad (1)$$

where $EPS_{i,t+1}$ and $EPS_{i,t+2}$ denote analysts' consensus forecasts of earnings per share for firm i in years $t+1$ and $t+2$, respectively, and P_{it} is the stock price of firm i at the end of year t. Analyst forecast data are obtained from the CSMAR database. Following the standard practice in the PEG model literature, this study excludes observations with missing future earnings forecasts or for which $EPS_{i,t+2} - EPS_{i,t+1} \leq 0$, and other observations that do not satisfy the conditions required for valid model estimation, so as to ensure the economic interpretability and comparability of the estimated cost of equity capital.

It should be noted that the estimation of the implied cost of equity capital based on the PEG model relies on analyst earnings forecast data; accordingly, the sample includes only firm-year observations for which the cost of equity capital can be calculated. Given that policy implementation may affect analyst coverage and the availability of earnings forecasts, the subsequent robustness tests further examine whether SO_2 emissions trading affects analyst coverage and the computability of the cost of equity capital and re-estimate the baseline model using a stable-coverage subsample and alternative measures of the cost of equity capital.

(3) Mechanism variables

To examine the potential channels through which SO_2 emissions trading affects firms' cost of equity capital, this study further constructs three mechanism variables: green innovation, ESG disclosure, and institutional ownership.

Green innovation (Patent): This study measures firms' green innovation by the annual number of green patent applications. Green patents are identified based on the green patent classification labels provided by the CNRDS patent database, and Patent is defined as the natural logarithm of one plus the number of green patent applications filed by a firm in a given year. The logarithmic transformation is used to mitigate the influence of the right-skewed distribution and extreme values in patent data. Green patent data are obtained from the CNRDS patent database.

ESG performance (ESG): This study uses firms' annual ESG ratings issued by the Huazheng Index to measure overall ESG performance. The Huazheng ESG rating system is designed for issuers in China's capital market and provides a comprehensive evaluation based on environmental (E), social (S), and governance (G) dimensions. Following common practice in the literature, this study converts the ESG ratings into a numerical variable and further standardizes it to ensure comparability across years and across firms. A higher value indicates better ESG performance and a stronger level of sustainable governance.

Institutional ownership (InstOwn): This study measures institutional investor participation by the proportion of shares held by institutional investors at the end of the year, defined as the total number of shares held by all types of institutional investors divided by the firm's total outstanding shares at year-end. This indicator captures the degree of participation of professional investors in the firm's ownership structure, as well as their potential role in information governance. Institutional ownership data are obtained from the CSMAR database.

(4) Control variables

To account for firm heterogeneity and mitigate omitted-variable bias, this study includes a set of firm-level control variables commonly used in the corporate finance and capital market literature. These include firm size (Size), measured as the natural logarithm of total assets; leverage (Lev), measured as total liabilities divided by total assets; revenue growth (Growth), defined as the year-on-year growth rate of operating revenue; return on equity (ROE), capturing firm profitability; total asset turnover (TAT), measuring operating efficiency; and the book-to-market ratio (BM), defined as the book value of equity divided by the market value of equity. This study also controls for ownership structure variables, including the separation of ownership and control rights (Separation), the shareholding ratio of the largest shareholder (Top1), and the combined shareholding ratio of the top ten shareholders (Top10).

(5) Grouping variables for heterogeneity analysis

To conduct heterogeneity analysis, this study further constructs three grouping variables: ownership type, environmental enforcement intensity, and financing constraints.

Ownership type: A firm is classified as a state-owned enterprise if its ultimate controller is the state or a state-owned legal entity; otherwise, it is classified as a non-state-owned enterprise.

Environmental enforcement intensity: This study uses the number of provincial environmental administrative penalty cases to measure regional environmental enforcement intensity and takes the natural logarithm of one plus this value. The relevant data are mainly obtained from the *China Environmental Statistical Yearbook* and publicly released environmental enforcement statistics from environmental authorities. To avoid endogenous grouping caused by using post-policy information, provinces are classified into high- and low-enforcement groups based on the sample median of the average environmental enforcement intensity in each province prior to policy implementation.

Financing constraints: This study employs the SA index proposed by Hadlock and Pierce (2010) [31] to measure the degree of firms' financing constraints. Constructed from firm size and firm age, the SA index helps alleviate reverse-causality concerns arising from endogenous financial variables. The specific formula is as follows:

$$SA = -0.737 \times Size + 0.043 \times Size^2 - 0.040 \times Age \quad (2)$$

where Size is the natural logarithm of total assets and Age is the number of years since the firm was established. A larger absolute value of the SA index generally indicates more severe financing constraints. Based on the sample median of firms' average SA index prior to policy implementation, this study classifies firms into high- and low-financing-constraint groups. The data required to construct the SA index are obtained from the CSMAR database.

Figure 2 plots the average cost of equity for firms in pilot and non-pilot provinces over time. The two groups exhibit broadly similar movements prior to 2007. After the policy implementation, the trend in pilot provinces decreases relative to non-pilot provinces, with the divergence becoming more visible in the post-policy years, which is consistent with a gradual adjustment process under market-based environmental regulation.



Figure 2. Trends in the average cost of equity capital in non-pilot and pilot regions.

3.2. Baseline Regression Model

To estimate the causal effect of the sulfur dioxide emissions trading system pilot on firms' cost of equity capital, this research used a dual-way fixed-influence model difference-in-differences framework. The empirical strategy exploits cross-provincial variation in policy implementation and within-firm variation over time, thereby isolating the effect of the emissions trading policy resulting from intrinsic attributes of organizations and prevalent macroeconomic disturbances. The baseline empirical specification is expressed as

$$COEit = \alpha + \beta 1(Post_t \times Treat_i) + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

The dependent variable is the implied cost of equity capital of firm i in year t, measured using the PEG-based approach described in Section 3.1. The key explanatory variable captures firm exposure to the sulfur dioxide emissions trading system after policy implementation. The set of control variables includes firm size, leverage, revenue growth, profitability, operational efficiency, valuation characteristics, and ownership structure variables. Firm fixed effects control for unobserved firm-specific attributes that are constant over time, while year fixed effects absorb aggregate shocks affecting all firms. Standard errors are estimated using heteroskedasticity-robust procedures and clustered at the provincial level to account for the province-level assignment of the policy.

4. Empirical Analysis

4.1. Baseline Results

The benchmark regressions reported in Table 2 include a comprehensive set of firm-level control variables to account for heterogeneity that may influence equity financing costs and the effectiveness of emissions trading policies. The recommended model specification, which includes firm and year fixed effects, is shown in Column (2) of Table 2. This provides a foundation for understanding the control variable estimates.

Table 2. Impact of SO_2 emissions trading pilot policy on firms' cost of equity capital.

	Pooled OLS	**Two-Way Fixed Effects**
	COE	**COE**
Post × Treat	−0.612 ***	−0.590 ***
	(−2.85)	(−2.75)
Size	−0.128 ***	−0.095 ***
	(−4.06)	(−3.02)
Lev	0.418 ***	0.362 ***
	(3.82)	(3.18)
Growth	−0.021	−0.014
	(−1.07)	(−0.85)
ROE	−0.298 **	−0.251 *
	(−2.24)	(−1.92)
TAT	−0.082 *	−0.058
	(−1.74)	(−1.18)
BM	0.142 ***	0.118 ***
	(4.05)	(3.47)
Separation	0.087	0.066
	(1.08)	(0.86)
Top1	−0.214 **	−0.176 **
	(−2.36)	(−2.05)
Top10	−0.147 ***	−0.119 **
	(−2.96)	(−2.41)
Observations	10,437	10,437
Adjusted R^2	0.850	0.860
Firm fixed effects	No	Yes
Year fixed effects	Yes	Yes
Region fixed effects	Yes	No
Industry fixed effects	Yes	No

Notes: Column (1) reports pooled OLS estimates controlling for year, region, and industry fixed effects, while Column (2) reports two-way fixed-effect estimates controlling for firm and year fixed effects. All continuous variables are winsorized at the 1st and 99th percentiles. Given that the pilot SO_2 emissions trading policy is implemented at the provincial level. t-statistics are reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Firm size is negatively and statistically significantly associated with the cost of equity capital. As shown in Column (2) of Table 2, the estimated coefficient on firm size is −0.095, indicating that larger firms face lower required returns from equity investors. This result is consistent with evidence from Chinese listed firms suggesting that firm size captures information transparency, operational stability, and risk diversification capacity, all of which reduce equity financing costs [32].

Capital structure exerts a positive influence on equity pricing. The leverage ratio has a statistically significant beneficial correlation value of 0.362 in Column (2) of Table 2. This finding reflects the amplification of financial risk and cash-flow volatility associated with higher debt exposure, which increases the risk borne by equity holders and raises the required rate of return. This result is in line with existing empirical evidence that highly leveraged firms incur higher equity financing costs [33].

ROE is negatively related to the cost of equity capital. The estimated coefficient on return on equity in Column (2) of Table 2 is −0.251 and statistically significant, indicating that firms with stronger earnings performance experience lower equity financing costs. Higher profitability reduces downside risk and enhances investor confidence in firms' future cash flows, consequently reducing the equity risk premium. This tendency aligns with prior findings for Chinese capital markets [32].

Ownership concentration also plays a meaningful role in equity pricing. In Table 2, as stated in Column (2), the shareholding ratio of the largest shareholder is associated with a negative and statistically significant coefficient of −0.176. This result supports the monitoring hypothesis in corporate governance, suggesting that concentrated ownership structures mitigate agency problems and reduce the risk premium demanded by external investors.

Other control variables, including revenue growth, total asset turnover, book-to-market ratio, and ownership–control separation, do not materially affect the estimated policy coefficient in Column (2) of Table 2. The inclusion of these controls does not alter the magnitude or significance of the emissions trading policy effect, confirming that the baseline results are not driven by concurrent changes in firm fundamentals or governance characteristics.

From an economic perspective, the sulfur dioxide emissions trading system initially increases compliance-related expenditures for regulated firms. Over time, however, the market-based design of the policy induces firms to adjust production decisions, improve environmental management practices, and undertake cleaner investments. These adjustments improve firms' perceived risk profiles and earnings sustainability, which are reflected in lower equity risk premiums and reduced cost of equity capital.

As China's first large-scale market-oriented environmental regulatory mechanism, the sulfur dioxide emissions trading system demonstrates that environmental regulation can improve capital market efficiency by lowering firms' equity financing costs. By aligning environmental objectives with financial incentives, the policy provides empirical support for the compatibility of environmental protection and financial performance within emerging market economies.

4.2. Parallel Trend Test

To examine the validity of the difference-in-differences identification strategy, we test the parallel trend assumption using an event-study specification that creates an interaction between the treatment indicator and a series of leads and lags relative to the implementation of the SO_2 emissions trading system. The year prior to the policy adoption acts as the reference period. The estimated dynamic coefficients are reported in Figure 3. Prior to 2007, the estimated coefficients fluctuate closely around zero and are statistically insignificant at conventional levels, indicating that before the implementation of policy intervention,

companies in both pilot and non-pilot provinces had similar patterns in equity capital costs. This evidence supports the key identifying assumption underlying the DID framework. Following the introduction of the SO_2 ETS, the coefficients gradually turn negative and increase in magnitude over time. In particular, the post-policy coefficients become statistically significant starting around 2010–2011, with point estimates reaching approximately −1.0 to −1.5 in later years, as shown in Figure 3. This pattern suggests that the reduction in firms' cost of equity capital is not immediate but emerges after a period of adjustment. Such a lagged response is consistent with the nature of market-based environmental regulation. Firms must first internalize emission prices, undertake green investment, and improve environmental management practices before capital market participants revise their assessments of firm-level risk. This gradual adjustment process accords with Williamson's theory of cognitive institutional change, which emphasizes that economic agents require time to recognize and respond to newly established property rights and regulatory signals [34]. It is also consistent with preliminary empirical studies on the EU Emissions Trading System, where firms typically needed several years to adapt to allowance trading mechanisms and incorporate them into financing and investment decisions [35].

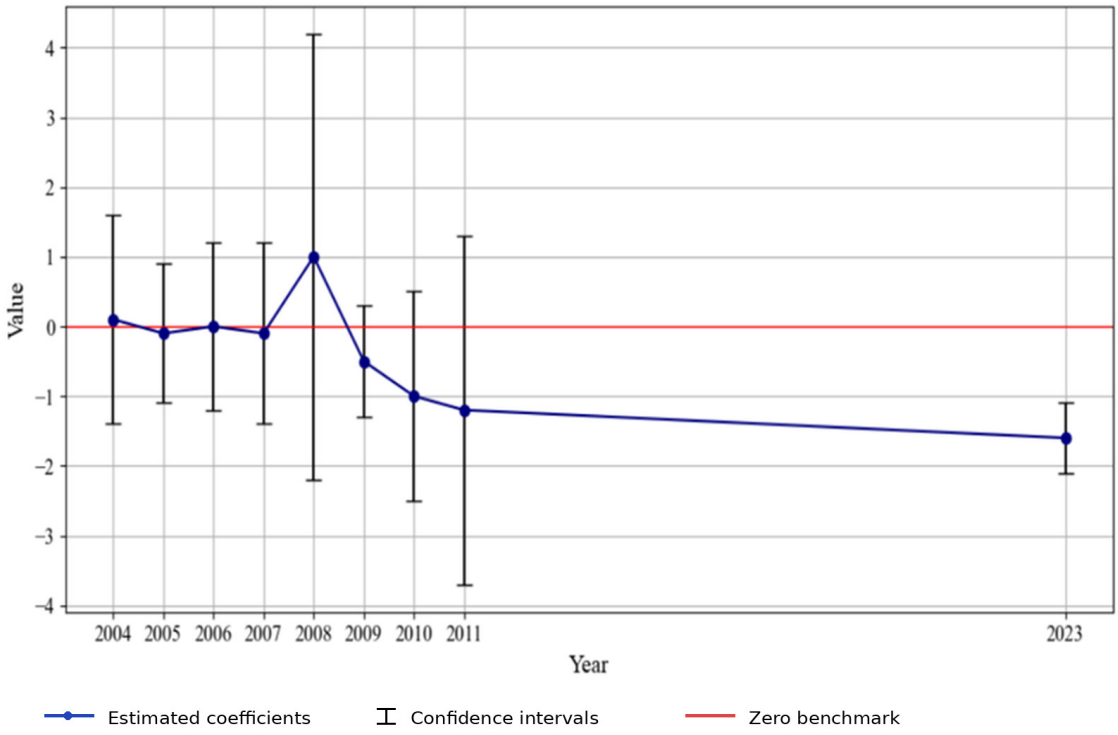

Figure 3. Parallel trend test results.

4.3. Mechanism Analysis

This section further examines the potential channels through which SO_2 emissions trading affects firms' cost of equity capital. In line with the research hypotheses developed in Section 2, this study focuses on three possible mechanisms: green innovation, ESG disclosure, and institutional ownership. To align the mechanism tests with the theoretical hypotheses, this study adopts a two-step approach. First, it examines whether SO_2 emissions trading significantly affects the mechanism variables themselves. Second, it investigates whether these mechanism variables strengthen the effect of the policy on firms' cost of equity capital.

First, this study estimates the following difference-in-differences model to test whether SO_2 emissions trading significantly affects the mechanism variables:

$$M_{it} = \alpha + \beta_1(Post_t \times Treat_i) + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

where M_{it} denotes green innovation (*Patent*), ESG disclosure (*ESG*), and institutional ownership (*InstOwn*), respectively, while the definitions of the other variables are consistent with those in the baseline model. The significance of β_1 is used to test whether SO_2 emissions trading significantly enhances the relevant mechanism variables. Table 3 reports the results of this first-stage analysis.

Table 3. Regression results of the mechanism test.

Variables	(1) Green Innovation (Patent)	(2) ESG Disclosure (ESG)	(3) Institutional Ownership (InstOwn)
Post × Treat	0.146 **	0.284 ***	0.173 **
	(2.21)	(3.67)	(2.54)
Constant	1.982 ***	0.316 ***	0.127 ***
	(4.85)	(5.42)	(4.96)
Control variables	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	10,437	10,437	10,437
R^2	0.781	0.846	0.803

Notes: t-statistics are reported in parentheses **, and *** denote significance at the 5%, and 1% levels, respectively.

Building on this, this study further estimates the following interaction model to examine whether the relevant mechanism variables strengthen the effect of the policy on firms' cost of equity capital:

$$COE_{it} = \delta_0 + \delta_1(Post_t \times Treat_i \times A_{it}) + \delta_2(Post_t \times Treat_i) + \delta_3 A_{it} + \lambda X_{it} + \gamma_t + \mu_i + \varepsilon_{it} \quad (5)$$

where A_{it} denotes green innovation (*Patent*), ESG disclosure (*ESG*), and institutional ownership (*InstOwn*) in different regressions and μ_i and γ_t represent firm fixed effects and year fixed effects, respectively. In all regressions, the dependent variable is the cost of equity capital (*COE*), and standard errors are clustered at the provincial level. A significantly negative coefficient on the triple interaction term indicates that the negative effect of SO_2 emissions trading on firms' cost of equity capital is stronger when the corresponding mechanism variable is at a higher level, thereby providing further supportive evidence for the relevant mechanism.

Table 3 reports that the coefficient on *Post* × *Treat* is significantly positive for all three mechanism variables (*Patent*: 0.146, $t = 2.21$; *ESG*: 0.284, $t = 3.67$; *InstOwn*: 0.173, $t = 2.54$), suggesting that after policy implementation, pilot firms experienced systematic increases in innovation activity, ESG disclosure, and institutional investor participation. Table 4 further shows that the cost-reducing effect of SO_2 emissions trading is more pronounced among firms with stronger green innovation capability, better ESG disclosure, and higher institutional ownership. Overall, these results are consistent with the theoretical predictions of Hypotheses 1, 2, and 3 and provide supportive evidence that SO_2 emissions trading affects firms' cost of equity capital through three channels: green innovation, ESG disclosure, and institutional ownership. It should be noted that the triple interaction results primarily capture heterogeneity in the policy effect across firm characteristics; therefore, they are more appropriately interpreted as consistent evidence on potential channels rather than as a strict causal identification of mediation effects.

Table 4. Regression results of the mechanism test (dependent variable: COE).

Variables	(1) Green Innovation (Patent)	(2) ESG Disclosure (ESG)	(3) Institutional Ownership (InstOwn)
Post × Treat × Patent	−0.210 **		
	(−2.12)		
Patent	0.045		
	(0.63)		
Post × Treat × ESG		−0.275 ***	
		(−3.90)	
ESG		0.090 *	
		(1.78)	
Post × Treat × InstOwn			−0.240 ***
			(−2.98)
InstOwn			−0.118 **
			(−2.41)
Constant	6.080 ***	5.610 ***	4.920 ***
	(5.72)	(5.88)	(5.10)
R-squared	0.945	0.950	0.942
Control variables	Yes	Yes	Yes
Industry fixed effects	No	No	No
Year fixed effects	Yes	Yes	Yes
Region fixed effects	No	No	No
Firm fixed effects	Yes	Yes	Yes

Notes: t-statistics are reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

4.4. Heterogeneity Analysis

In order to further assess whether the impact of sulfur dioxide emissions trading systems varies across firms and institutional environments, this study examines the heterogeneous effects of these systems across three economically significant dimensions: firm ownership structure, regional environmental enforcement intensity and financing constraints. The analysis proceeds as follows:

First, state-owned enterprises (SOEs) have institutional advantages when it comes to alleviating financing constraints and dispersing risks, thanks to implicit government guarantees (Ren et al., 2020; Liu et al., 2024) [15,19]. In contrast, private enterprises lack government support, face stringent market constraints and are more sensitive to financing fluctuations. Therefore, we expect private enterprises to exhibit more pronounced equity capital cost volatility than SOEs when the carbon trading system intensifies compliance burdens and operational risks.

Secondly, the intensity of regional environmental enforcement affects the effectiveness of sulfur dioxide emissions trading schemes. Corporate emissions performance influences equity capital costs by altering compliance costs, adjusting operational risks and affecting investor risk perceptions. Consequently, we anticipate that the impact of emissions trading schemes on equity capital costs will be more pronounced in regions with stringent environmental regulations.

Thirdly, from an institutional theory perspective, firms' responses to environmental regulations are driven by external policy requirements but are also constrained by internal resource availability and financing limitations. Firms with higher financing constraints find it difficult to absorb regulatory costs and the impact of market volatility, making them more vulnerable to rising compliance costs and increased uncertainty when market-based environmental policies such as emissions trading are implemented. Conversely, firms with weaker financing constraints have more stable funding sources and more transparent

financial disclosures, which can mitigate the impact of environmental regulation shocks on their equity capital costs to some extent. Therefore, we anticipate that the emissions trading system will have a greater impact on the equity capital costs of firms facing stronger financing constraints.

The heterogeneity analysis is tested as follows:

First, the sample is grouped based on the three aforementioned indicators. Specifically, we use a priori criteria to subdivide the sample, avoiding endogeneity issues: firms with state-owned ultimate controlling shareholders are classified as state-owned enterprises (SOEs), while others are non-state-owned enterprises (NSOEs). Provincial-level environmental enforcement intensity is measured using the logarithm of the number of environmental administrative penalty cases at provincial level plus one. Based on the median pre-policy implementation enforcement intensity across the sample, provinces are grouped into high- and low-enforcement categories. Financing constraints are measured using the SA index, which is constructed based on firm size and age. Firms are divided into high- and low-constraint groups based on the median sample value of the average SA index prior to policy implementation. All subsample divisions employ fixed criteria and do not utilize forward-looking information.

Secondly, a benchmark difference-in-differences model is estimated for each subsample separately. This approach ensures flexibility in treatment effects across groups while maintaining consistent model structures for all estimates. Specifically, the subsample benchmark model is specified as follows:

$$COE_{it} = \beta_0 + \beta_1 Post \times Treat + \lambda X_{it} + \gamma_t + \mu_i + \varepsilon_{it} \quad (6)$$

In Equation (6), $COE_{i,t}$ denotes the implied cost of equity capital of firm i in year t. The term $Post \times Treat$ captures firms' exposure to the SO_2 ETS after policy implementation. $X_{i,t}$ is the vector of firm-level control variables defined in Table 1. Firm fixed effects μ_i absorb time-invariant firm characteristics, and year fixed effects γ_t control for macro shocks common to all firms. Standard errors are clustered at the provincial level to reflect province-level policy assignment.

Columns (1) and (2) of Table 5 report the results by ownership structure. The estimated coefficient on $Post \times Treat$ is negative for both groups but statistically significant only for non-state-owned firms. Specifically, the coefficient for non-state-owned enterprises is -0.890 with a t-statistic of -2.07, whereas the estimate for state-owned enterprises is smaller in magnitude and statistically insignificant. This pattern is consistent with stronger market discipline and greater sensitivity to investor risk pricing among non-state-owned firms, while implicit government support and relatively stable financing channels may dampen the response of state-owned enterprises.

Columns (3) and (4) examine heterogeneity across regions with different levels of environmental enforcement intensity. In high-enforcement regions, the estimated policy effect is economically meaningful and statistically significant: the coefficient on $Post \times Treat$ equals -0.930 with a t-statistic of -3.50. In low-enforcement regions, the estimated effect is smaller and statistically insignificant. This divergence implies that the capital market impact of emissions trading depends critically on implementation credibility. When enforcement is strong, the ETS signal is more informative about future compliance costs and environmental risk exposure, making it more relevant for equity risk pricing.

Columns (5) and (6) report results by financing constraints. The ETS effect is most pronounced among financially constrained firms, with an estimated coefficient of -1.020 and a t-statistic of -3.15, while the estimate for firms with low constraints is statistically insignificant. This finding suggests that policy-induced improvements in perceived risk and the information environment translate into larger equity cost reductions for firms

whose external financing conditions are more sensitive to changes in risk premia. Firms facing fewer financing frictions already have relatively favorable capital market access, leaving less scope for additional policy-driven reductions in the cost of equity.

Table 5. Heterogeneity analysis: subsample regression results.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	Ownership Structure		Environmental Enforcement		Financing Constraints	
	State-Owned	Non-State-Owned	High Enforcement	Low Enforcement	High Financing Constraints	Low Financing Constraints
Post × Treat	−0.360	−0.890 **	−0.930 ***	−0.470	−1.020 ***	−0.310
	(−1.32)	(−2.07)	(−3.50)	(−1.28)	(−3.15)	(−1.05)
Constant	2.380	12.100 *	1.310	8.250	3.940	7.860
	(0.27)	(1.28)	(0.20)	(1.02)	(0.48)	(0.95)
Observations	6976	3461	5385	5052	5210	5227
R-squared	0.910	0.925	0.930	0.905	0.928	0.907
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes

Notes. Each column reports estimates from Equation (5) on the corresponding subsample. All regressions include the control variables in Table 1, firm fixed effects, and year fixed effects. Standard errors are clustered at the provincial level. t-statistics are reported in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Taken together, the heterogeneity results show that the SO_2 ETS effect on the cost of equity is not uniform. The policy is most effective in reducing equity financing costs where market discipline is stronger, enforcement credibility is higher, and financing frictions are more severe. These patterns highlight the importance of institutional context in shaping the capital market consequences of market-based environmental regulation.

To formally test whether the policy effect differs across groups, this study further estimates pooled interaction models rather than relying solely on differences in significance across separate subsample regressions. Specifically, we construct triple interaction terms between the policy shock and group dummy variables and estimate the following model:

$$COE_{it} = \alpha + \beta_1(Post_t \times Treat_i) + \beta_2(Post_t \times Treat_i \times H_i) + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (7)$$

where H_i denotes the group indicator, alternatively defined as a dummy for non-state-owned enterprises (NonSOE), a dummy for firms located in high-enforcement regions (HighEnforce), and a dummy for firms facing high financing constraints (HighFC). Since H_i is time-invariant, its main effect is absorbed by firm fixed effects and is therefore not reported separately. The coefficient β_2 is used to test whether the treatment effect differs significantly across groups. A significantly negative β_2 indicates that, relative to the reference group, the SO_2 emissions trading pilot has a significantly stronger effect in reducing firms' cost of equity capital for the corresponding group.

Table 6 reports the estimation results from the pooled interaction models. The coefficient on $Post \times Treat \times NonSOE$ is −0.528 and is significant at the 5% level, indicating that the SO_2 emissions trading policy has a significantly stronger effect in reducing the cost of equity capital for non-state-owned enterprises than for state-owned enterprises. The coefficient on $Post \times Treat \times HighEnforce$ is −0.462, also significant at the 5% level, suggesting that the capital market effect of the policy is significantly stronger in high-enforcement regions than in low-enforcement regions. Similarly, the coefficient on $Post \times Treat \times HighFC$ is −0.714 and significant at the 1% level, indicating that the policy has a significantly stronger cost of equity-reducing effect for firms facing higher financing constraints.

Table 6. Formal tests of heterogeneous effects: pooled interaction model results.

Variable	(1) Ownership Structure	(2) Environmental Enforcement	(3) Financing Constraints
Post × Treat	−0.362 (−1.31)	−0.468 (−1.27)	−0.308 (−1.03)
Post × Treat × NonSOE	−0.528 ** (−2.04)	—	—
Post × Treat × HighEnforce	—	−0.462 ** (−2.11)	—
Post × Treat × HighFC	—	—	−0.714 *** (−2.67)
Control variables	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	10,437	10,437	10,437
R^2	0.862	0.864	0.866

Notes: t-statistics are reported in parentheses **, and *** denote significance at the 5%, and 1% levels, respectively.

Overall, the heterogeneity analysis suggests that the effect of the SO_2 emissions trading policy on reducing firms' cost of equity capital is not uniform across firms. Rather, it is more pronounced in settings characterized by stronger market discipline, higher enforcement credibility, and more severe financing frictions. It should be noted that the subsample regressions are primarily intended to illustrate heterogeneous patterns of policy effects across different contexts, whereas the pooled interaction models provide formal statistical tests of coefficient differences across groups. The two sets of evidence are consistent in direction, thereby offering more robust support for our conclusions regarding heterogeneous policy effects.

4.5. Robustness Tests

To further verify the robustness of the baseline results, this study conducts a series of additional tests from the perspectives of random placebo tests, small-cluster robust inference, placebo policy timing, and the sequential exclusion of pilot provinces. Given that the pilot SO_2 emissions trading policy is implemented at the provincial level, all of the following tests consistently control for the variables listed in Table 1 and include firm fixed effects and year fixed effects and cluster standard errors at the provincial level.

4.5.1. Placebo Test

To assess whether the benchmark estimates could be driven by unobserved confounders and whether the baseline estimation results are driven by unobserved confounding factors, spurious correlations, or the randomness of provincial policy assignment, this study conducts a placebo test based on the random reassignment of the policy at the provincial level. This placebo design preserves the institutional feature of the SO_2 emissions trading policy, namely that treatment is assigned at the provincial rather than the firm level.

Specifically, in each simulation, a set of provinces equal in number to the actual pilot provinces is randomly selected as pseudo-pilot provinces, while the policy implementation timing is kept unchanged. The baseline difference-in-differences model is then re-estimated using the same sample, control variables, and fixed effects as in the baseline regression, and the coefficient on *Post* × *Treat* is recorded. This procedure is repeated 1000 times, thereby generating the empirical distribution of placebo treatment effects under the null hypothesis that treatment assignment is unrelated to the dynamics of firms' cost of equity capital.

Figure 4 presents a comparison between the placebo distribution and the baseline estimate. The placebo coefficients are tightly centered around zero, with most estimates falling within a narrow interval near zero. In contrast, the baseline estimate of *Post* × *Treat*

reported in Table 2 is approximately −0.590, which lies in the left tail of the placebo distribution and is clearly separated from the vast majority of placebo estimates. This result suggests that the observed decline in firms' cost of equity capital is unlikely to be explained by general time trends, random provincial selection, or other province-level fixed shocks unrelated to the SO_2 emissions trading policy but is instead systematically associated with the actual policy implementation.

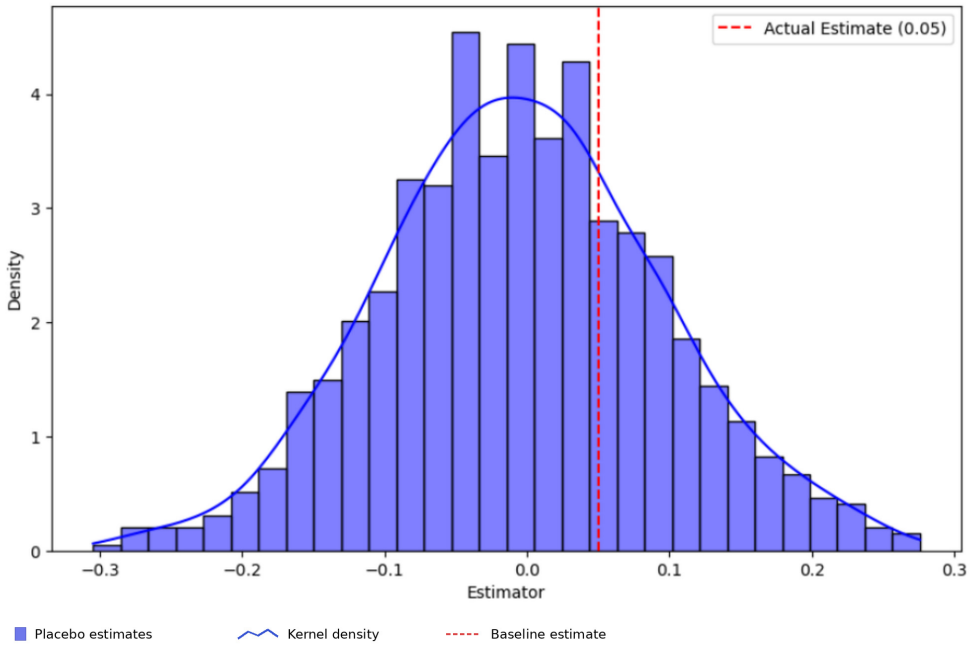

Figure 4. Distribution of estimated Post × Treat coefficients from 1000 placebo simulations.

4.5.2. Small-Cluster Robust Inference

Because the treatment variable in this study is assigned at the provincial level and the number of clusters is relatively limited, conventional province-clustered robust standard errors may underestimate the uncertainty of the estimates. To address this concern, this study further employs the wild cluster bootstrap method to reassess the significance of the core explanatory variable, *Post* × *Treat*, at the provincial clustering level, thereby obtaining more reliable statistical inference for settings with a small number of clusters. In the baseline regression, the estimated coefficient on *Post* × *Treat* is −0.590, with a province-clustered t-statistic of −2.75 and a corresponding wild cluster bootstrap p-value of 0.021. This result indicates that, after accounting for the potential inference bias arising from the limited number of clusters, the negative effect of the pilot SO_2 emissions trading policy on firms' cost of equity capital remains statistically significant, suggesting that the baseline conclusion is not driven by significance bias induced by a small number of clusters.

4.5.3. Placebo Policy Timing Test

To further rule out the possibility that the results are driven by other contemporaneous shocks or by systematic pre-existing differences between the treatment and control groups before policy implementation, this study conducts a placebo policy timing test. Specifically, while keeping the treatment group definition unchanged, the policy implementation year is artificially advanced to 2006 and 2005, respectively. Based on these alternative timing assumptions, placebo policy timing variables are reconstructed and the baseline difference-in-differences model is re-estimated. If the main findings are indeed driven by the actual policy implementation, the coefficient on *FakePost* × *Treat* should not be statistically significant under these placebo policy years.

Table 7 reports the results of the placebo policy timing test. When the policy implementation year is artificially moved forward to 2006, the estimated coefficient on the placebo treatment term, *FakePost* × *Treat*, is −0.118, with a *t*-statistic of −0.64. When the policy year is further advanced to 2005, the estimated coefficient is −0.086, with a *t*-statistic of −0.47. Neither estimate reaches conventional levels of statistical significance. These results indicate that the baseline findings are not driven by pre-policy trend differences or other common shocks occurring prior to the actual policy implementation, thereby providing further support for the validity of the difference-in-differences identification strategy.

Table 7. Placebo policy timing test.

Variables	(1) Assuming Implementation in 2006	(2) Assuming Implementation in 2005
FakePost × Treat	−0.118	−0.086
	(−0.64)	(−0.47)
Control variables	Yes	Yes
Firm fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Observations	10,437	10,437
R^2	0.857	0.856

4.5.4. Leave-One-Pilot-Province-Out Test

Given that the pilot SO_2 emissions trading policy was implemented in only 11 provincial-level administrative regions, the baseline results may potentially be influenced by individual pilot provinces. To address this concern, this study further conducts a leave-one-pilot-province-out test. Specifically, in each iteration, one pilot province is excluded from the treatment group, the baseline difference-in-differences model is re-estimated, and the sign, magnitude, and statistical significance of the core explanatory variable, *Post* × *Treat*, are examined for systematic changes.

The model is re-estimated after sequentially excluding each of the 11 pilot provinces—Tianjin, Jiangsu, Zhejiang, Hubei, Chongqing, Hunan, Inner Mongolia, Hebei, Shaanxi, Henan, and Shanxi—and the results are reported in Table 8. The coefficient on *Post* × *Treat* remains consistently negative across all specifications, ranging from −0.533 to −0.648, with corresponding *t*-statistics ranging from −2.41 to −2.93. The main conclusion remains substantively unchanged. These results indicate that the finding that the pilot SO_2 emissions trading policy reduces firms' cost of equity capital is not driven by any single pilot province but instead exhibits strong sample robustness.

Table 8. Leave-one-pilot-province-out test.

Excluded Pilot Province	Coefficient on Post × Treat	*t*-Statistic
Tianjin	−0.571 **	−2.63
Jiangsu	−0.648 ***	−2.93
Zhejiang	−0.602 **	−2.71
Hubei	−0.557 **	−2.52
Chongqing	−0.533 **	−2.41
Hunan	−0.589 **	−2.68
Inner Mongolia	−0.614 **	−2.76
Hebei	−0.581 **	−2.59
Shaanxi	−0.566 **	−2.54
Henan	−0.597 **	−2.70
Shanxi	−0.608 **	−2.74
Shanxi	−0.608 **	−2.74

Notes: t-statistics are reported in the third column. ** and *** denote significance at the 5% and 1% levels, respectively.

4.5.5. Instrumental Variable Test

Although the SO_2 emissions trading system is implemented at the provincial level, the selection of pilot provinces may still be correlated with unobserved regional factors, such as pollution dispersion conditions, environmental carrying capacity, industrial structure, and baseline pollution intensity. These factors may affect both the assignment of pilot status and firms' financing conditions through the regional economic environment, thereby introducing potential endogeneity into the baseline difference-in-differences estimates. To mitigate this concern, this study employs a two-stage least-squares (2SLS) approach and uses the interaction between the provincial ventilation coefficient and the post-policy dummy, $VC_{pt} \times Post_t$, as an instrumental variable for the policy shock term, $Post_t \times Treat_i$.

The ventilation coefficient (VC) measures a region's natural capacity to disperse air pollutants. A higher value indicates higher wind speed and a greater atmospheric boundary layer height, implying that pollutants can diffuse more easily and that pollutant accumulation is relatively lower. Conversely, regions with lower ventilation coefficients are more prone to pollutant retention and accumulation and thus are more likely to face stronger environmental regulatory pressure. Therefore, $VC_{pt} \times Post_t$ can effectively explain the likelihood of a region being included in the pilot program after policy implementation, satisfying the relevance condition for a valid instrumental variable.

With respect to exogeneity, the ventilation coefficient is primarily determined by meteorological and geographic conditions, and its variation is driven by natural factors such as near-surface wind speed and atmospheric boundary layer height. It is therefore unlikely to affect firms' cost of equity capital directly through corporate governance, operating decisions, or investor behavior. After controlling for firm fixed effects, year fixed effects, and firm-level covariates, the ventilation coefficient is expected to affect firms mainly through regional environmental regulatory pressure and the probability of policy inclusion, thereby providing a strong basis for exogeneity.

This study constructs the ventilation coefficient using hourly meteorological data for Chinese prefecture-level cities from 2003 to 2023. Specifically, the data are obtained from the ERA5 reanalysis dataset of the European Centre for Medium-Range Weather Forecasts (ECMWF). For each prefecture-level city, this study multiplies hourly wind speed by the atmospheric boundary layer height at the corresponding hour and then sums these hourly values over the entire year to obtain the city-level annual ventilation coefficient. It then aggregates the annual ventilation coefficients of all cities within the same province to construct the provincial annual ventilation coefficient. The calculation is as follows:

$$VC_{pt} = \sum_{c \in p} \sum_{h=1}^{H} (u_{cht} \times h_{cht}) \tag{8}$$

where u_{cht} denotes the wind speed of city c in province p at hour h in year t, h_{cht} denotes the atmospheric boundary layer height at the same point in time, and H is the total number of hours in a year. The resulting interaction term, $VC_{pt} \times Post_t$, is used as the excluded instrument in the first stage.

The 2SLS estimation equations are as follows:

First stage:

$$Post_t \times Treat_i = \pi_0 + \pi_1 (VC_{pt} \times Post_t) + \theta X_{it} + \mu_i + \gamma_t + \nu_{it} \tag{9}$$

Second stage:

$$COE_{it} = \alpha_0 + \alpha_1 (\widehat{Post_t \times Treat_i}) + \beta X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \tag{10}$$

where $(\widehat{Post_t \times Treat_i})$ is the fitted value of the policy shock term obtained from the first stage and the definitions of the remaining variables are the same as those in the baseline model.

Table 9 reports the 2SLS estimation results. In the first-stage regression, the dependent variable is $Post \times Treat$, and the excluded instrument is $VC \times Post$, where VC denotes the provincial annual ventilation coefficient. In the second-stage regression, the dependent variable is firms' cost of equity capital (COE). The results show that, in the first stage, $VC \times Post$ is significantly negatively associated with $Post \times Treat$, with an estimated coefficient of −0.160 and a t-statistic of −9.30, indicating that provinces with weaker natural dispersion capacity were more likely to be included in the SO_2 emissions trading pilot after policy implementation. The Kleibergen–Paap rk Wald F-statistic is 86.49, well above the conventional threshold, suggesting that weak instrument concerns are not prominent. In the second stage, the estimated coefficient on the policy shock term remains significantly negative, indicating that, after accounting for the potential endogeneity of pilot selection, the SO_2 emissions trading system still significantly reduces firms' cost of equity capital. This finding confirms the robustness of the baseline results. Because the model is exactly identified, with one excluded instrument corresponding to one endogenous explanatory variable, an overidentification test is not applicable; accordingly, the Hansen J-statistic is not reported.

Table 9. Instrumental variable estimation results.

Variables	First-Stage Regression (Dependent Variable: Post × Treat)	Second-Stage Regression (Dependent Variable: COE)
VC × Post	−0.160 *	—
	(−9.30)	
Post × Treat	—	−5.150 *
		(−3.27)
Size	0.011	0.812 ***
	(1.35)	(4.62)
Lev	−0.006	0.401 ***
	(−0.88)	(3.10)
Growth	0.002	−0.018
	(0.55)	(−0.92)
ROE	−0.005	−0.287 **
	(−0.80)	(−2.14)
TAT	−0.003	−0.071
	(−0.60)	(−1.32)
BM	0.006	0.139 ***
	(1.20)	(3.85)
Separation	0.004	0.081
	(0.65)	(1.12)
Top1	−0.009	−0.198 **
	(−1.40)	(−2.28)
Top10	−0.012 **	−0.021 **
	(−2.10)	(−2.18)
Observations	10,437	10,437
R^2	0.710	0.820
Kleibergen–Paap rk Wald F-statistic	86.49 ***	—

Notes: All regressions include the control variables reported in Table 1, as well as firm fixed effects and year fixed effects. Standard errors are clustered at the provincial level. t-statistics are reported in parentheses, *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

4.5.6. Sample Selection and Alternative Measure Tests

Because this study measures firms' cost of equity capital using the PEG model, the measure relies on analysts' forecasts of firms' future earnings. As a result, the sample mechanically excludes firm-year observations lacking valid analyst forecast data or failing

to satisfy the model's computation requirements. If SO_2 emissions trading itself affects analyst coverage, forecast availability, or the computability of the cost of equity capital, the baseline sample may be subject to selective inclusion, thereby threatening the identification validity of the main regression results. To address this concern, this study conducts additional tests from the perspectives of sample selection and alternative measures.

First, this study examines whether SO_2 emissions trading affects analyst coverage and the computability of the cost of equity capital. Specifically, the number of analysts following a firm (Coverage) and a dummy variable indicating whether the cost of equity capital can be computed (COE_Available) are used as dependent variables in difference-in-differences specifications consistent with the baseline model. Columns (1) and (2) of Table 10 report the corresponding results. The coefficient on *Post* × *Treat* is 0.037 for analyst coverage, with a *t*-statistic of 0.48, and 0.012 for the computability of the cost of equity capital, with a *t*-statistic of 0.31. Neither coefficient is statistically significant at conventional levels. These findings indicate that SO_2 emissions trading does not systematically alter analyst forecasting behavior or the computability of the cost of equity capital, suggesting that the baseline sample is unlikely to suffer from substantial policy-induced selective inclusion.

Table 10. Sample selection and alternative measure tests.

Variables	(1) Analyst Coverage (Coverage)	(2) COE Computability (COE_Available)	(3) Stable-Coverage Sample (COE)	(4) Alternative COE Measure
Post × Treat	0.037	0.012	−0.563 **	−0.472 **
	(0.48)	(0.31)	(−2.61)	(−2.33)
Constant	1.284 ***	0.913 ***	6.041 ***	5.684 ***
	(6.12)	(18.45)	(5.27)	(5.03)
Control variables	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	10,437	10,437	8736	10,437
R^2	0.742	0.801	0.861	0.848

Notes: t-statistics are reported in parentheses **, and *** denote significance at the 5%, and 1% levels, re-spectively.

Second, this study re-estimates the baseline model using a stable-coverage subsample. Specifically, only firms with continuous analyst forecast records in the years prior to policy implementation are retained, so as to minimize potential sample selection bias arising from fluctuations in analyst coverage. Column (3) of Table 10 shows that, in the stable-coverage subsample, the estimated coefficient on *Post* × *Treat* is −0.563, with a *t*-statistic of −2.61, remaining significantly negative and close in magnitude to the baseline estimate. This result suggests that the finding that SO_2 emissions trading reduces firms' cost of equity capital does not depend on any particular sample composition generated by analyst forecast availability.

To ensure that the findings are not driven by a single implied cost of equity model, we further conduct a robustness test using an alternative measure. Specifically, in addition to the PEG model proposed by Easton (2004) [30], we further employ the Modified PEG (MPEG) model to construct an alternative implied cost of equity measure. The formula is given as follows:

$$COE_{it} = A + \sqrt{A^2 + \frac{EPS_{i,t+2} - EPS_{i,t+1}}{P_{it}}} \tag{11}$$

where

$$A = \frac{DPS_{i,t+1}}{2P_{it}} \tag{12}$$

$EPS_{i,t+1}$ and $EPS_{i,t+2}$ denote Analysts' Earnings-Per-Share Forecasts For Firm I for the first and second future years, respectively; $DPS_{i,t+1}$ denotes the forecasted dividend

per share for the first future year; and P_{it} is the current stock price of firm i. All relevant data are obtained from the CSMAR database. Following the standard implementation of the MPEG model, firm-year observations that do not satisfy the model's calculation requirements are excluded.

Column (4) of Table 10 reports the estimation results based on this alternative measure. The results show that, after recalculating the cost of equity capital using the MPEG model, the estimated coefficient on the core policy variable $Post \times Treat$ remains significantly negative, at -0.472 with a t-statistic of -2.33. This finding indicates that the conclusion that the SO_2 emissions trading pilot reduces firms' cost of equity capital is not driven by a particular estimator but remains stable across different implied cost of equity measures.

Overall, these results suggest that the baseline conclusion is neither primarily driven by selective changes in the analyst forecast sample nor dependent on the specific PEG-based measurement approach. Therefore, the main findings of this study can be regarded as robust.

5. Conclusions

Using a sample of 497 A-share listed firms in China's high SO_2-emitting industries over the period 2003–2023, this study examines the effect of the 2007 pilot SO_2 emissions trading policy on firms' cost of equity capital. A two-way fixed-effects difference-in-differences model is employed to identify the policy effect, and the reliability of the baseline results is further validated through parallel trend tests, instrumental variable estimation, and a series of robustness checks.

The results show that the pilot SO_2 emissions trading policy significantly reduces firms' cost of equity capital, indicating that market-based environmental regulation not only affects firms' pollution control behavior but also improves firms' financing conditions through the risk-pricing mechanism in capital markets. Further dynamic analysis suggests that the policy effect does not emerge immediately after implementation but gradually strengthens after an adjustment period, which is consistent with the process by which firms adapt to new environmental constraints, undertake green investment, and optimize their operating decisions.

The mechanism analysis shows that, following the implementation of the SO_2 emissions trading system, pilot firms experience improvements in green innovation, ESG disclosure, and institutional ownership. At the same time, the cost-reducing effect of the policy is more pronounced among firms with stronger green innovation capability, better ESG disclosure, and higher institutional ownership. These findings are consistent with the theoretical expectations proposed in this study, suggesting that the emissions trading system may affect capital market pricing of firm risk through channels such as promoting green innovation, improving the information environment, and optimizing investor structure. It should be noted that the mechanism tests in this study primarily capture heterogeneity in the policy effect across firms with different characteristics and are therefore more appropriately interpreted as supportive evidence for potential channels rather than as a strict causal identification of mediation effects.

The heterogeneity analysis further indicates that the capital market effect of the SO_2 emissions trading system is not evenly distributed but is more pronounced among non-state-owned firms, firms located in regions with stronger environmental enforcement, and firms facing tighter financing constraints. This suggests that the policy effect depends not only on the regulation itself but also on firms' governance characteristics, the institutional enforcement environment, and financing conditions. In other words, whether market-based environmental regulation can be effectively transmitted to capital markets depends to a

large extent on institutional credibility, firms' reliance on external financing, and investors' sensitivity to changes in risk.

In terms of robustness, this study further conducts placebo tests, small-cluster robust inference, placebo policy timing tests, leave-one-pilot-province-out tests, instrumental variable estimation, and sample selection and alternative measure tests. The results consistently indicate that the baseline findings are highly robust. This suggests that the effect of the pilot SO_2 emissions trading policy on firms' cost of equity capital is not driven by random shocks, sample selection bias, or specific model specifications.

The findings of this study carry several policy implications. First, the emissions trading system serves not only environmental governance objectives but also reduces the cost of equity financing by improving firms' risk profiles and information environment, thereby generating a synergistic effect between environmental goals and financial outcomes. Second, improving the quality of environmental information disclosure, strengthening enforcement intensity, and refining market-based trading rules can help enhance both the policy credibility of the emissions trading system and its informational content for capital markets. Finally, in advancing environmental regulatory reform, policymakers should take into full account differences in ownership structure, financing constraints, and regional institutional environments in order to enhance policy effectiveness.

This study also has several limitations. Although fixed effects, instrumental variables, and multiple robustness checks are employed to strengthen causal identification, it remains difficult to completely rule out the potential association between pilot selection and unobserved regional factors. In addition, the cost of equity capital is primarily measured using implied cost of equity models, and different models may capture risk premia differently. Future research could further examine the long-term capital market effects of emissions trading systems and their micro-level transmission mechanisms by incorporating higher-frequency data, richer policy variation, and more detailed measures of firm behavior.

Author Contributions: Conceptualization, X.L. and J.W. (Jinrui Wei); methodology, X.L. and J.W. (Jianzhou Wang); software, X.L.; validation, J.W. (Jinrui Wei), J.W. (Jianzhou Wang), and Y.G.; formal analysis, X.L.; investigation, X.L. and H.L.; resources, Y.G. and H.L.; data curation, X.L. and H.L.; writing—original draft preparation, X.L.; writing—review and editing, J.W. (Jinrui Wei), J.W. (Jianzhou Wang), Y.G., and H.L.; visualization, X.L.; supervision, J.W. (Jianzhou Wang) and Y.G.; project administration, Y.G.; funding acquisition, Y.G. and H.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Youth Project of the Liaoning Provincial Social Science Planning Fund (Grant No. L24CTJ001), the Science and Technology Program of Guizhou (No. Qian-Sci. Platform ZSYS[2024]003) and the Guizhou Philosophy and Social Sciences Innovation Team Construction Funding Project (No. CXTD2025009).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The empirical analysis was conducted using Stata/MP 18.0. The Stata code used in this study is available from the corresponding author upon reasonable request. The firm-level financial, governance, stock price, and patent-related data supporting the findings of this study were obtained from the GTA CSMAR database, the Hexun database, and the CNRDS database, respectively. These databases were accessed on 4 April 2025; some data require institutional subscription or registration for access.

Acknowledgments: Special thanks to He Zhu from Dongbei University of Finance and Economics for supporting the empirical study. We appreciate the insightful critiques from all reviewers and editors, and we take full accountability for any mistakes in this paper.

Conflicts of Interest: The author declares no conflicts of interest.

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