sustainability

MDPI

Article

Carbon Emission Trading, Green Technology Innovation, and Corporate ESG Performance: The Dual Moderation of Executives' Green Cognition and Environmental Policy Uncertainty

Guoyu Mao * and Luqian Xu

School of Management, Sichuan University of Science & Engineering, Yibin 644000, China; yueliangdangao@163.com

* Correspondence: guoyu_m@suse.edu.cn

Abstract

Carbon emission trading is a vital market-based instrument for corporate sustainable development. Treating China's carbon emission trading pilot as a quasi-natural experiment, this study employs panel data of A-share listed firms in high-carbon industries (2010–2023) and a time-varying difference-in-differences model to examine its effect on corporate ESG performance. The results confirm that carbon trading significantly enhances ESG performance. Beyond this, three key insights emerge. First, both executives' green cognition and environmental policy uncertainty positively moderate this relationship; notably, a three-way interaction reveals partial substitution between the two moderators at high levels, refining the capability–pressure coupling framework. Second, green technology innovation is a statistically significant but economically weak mediator. This weakness stems from an internal offset—the policy promotes substantive invention patents while suppressing incremental utility model patents—and alternative channels, particularly financing constraints and carbon disclosure quality, which serve as the primary transmission pathways. Third, the policy effect is more pronounced among heavily polluting firms and in eastern and central regions, reflecting differential regulatory exposure. These findings offer practical implications for carbon market expansion, green innovation incentives, regionally differentiated regulation, and the integration of carbon asset management with executives' green cognition development.

Keywords: carbon emission trading; corporate ESG performance; green technology innovation; influence mechanism

Academic Editor: Cristina Raluca Gh. Popescu

Received: 2 July 2026
Revised: 27 July 2026
Accepted: 29 July 2026
Published: 1 August 2026

1. Introduction

Carbon emission trading systems (ETSs) have evolved from regional policy experiments to a cornerstone of global climate governance. According to the ICAP 2026 Status Report, global carbon markets have accelerated their expansion amid climate shocks, geopolitical fragmentation, and economic uncertainty: 41 systems now cover 26% of global emissions and 63% of the global GDP, with growth increasingly concentrated in emerging economies. Carbon pricing has thus become deeply embedded in national development strategies and is a core institutional variable in assessing firms' long-term value. However, while the environmental and economic effects of carbon markets are well documented, how they translate into comprehensive corporate ESG improvements—and how organizational characteristics and institutional contexts moderate this transmission—remains underexplored.

China provides an ideal quasi-experimental setting to address these gaps. Its carbon emission trading, a market-based mechanism that internalizes environmental costs through allowance allocation, incentivizes proactive abatement and stimulates innovation more effectively than command-and-control approaches. Pilots were launched in seven provinces and municipalities in 2011, followed by the world's largest national carbon market by covered emissions in 2021; by the end of 2025, the cumulative trading volume had reached 8.65 billion tons. With emissions concentrated in eight high-carbon sectors—including power generation, steel, and building materials—firms in these industries serve as both primary abatement agents and natural subjects for examining the carbon pricing–ESG transmission pathway.

Against the backdrop of the "dual carbon" strategy (carbon peaking and carbon neutrality), ESG performance has emerged as a critical barometer of long-term corporate viability. Robust ESG performance not only alleviates financing constraints [1] and strengthens risk management [2], but also enhances market reputation and long-term value [3]. Carbon trading directly compels firms to optimize energy structures and upgrade production processes, thereby improving environmental performance, while active participation promotes environmental disclosure, bolsters stakeholder trust, and generates positive spillovers across social and governance dimensions. Green technology innovation—a vital pathway for achieving emission reduction targets—raises energy efficiency, lowers compliance costs, and secures competitive advantages under environmental regulations, a bridging role further reinforced in 2022, when the State Council issued the Implementation Plan for Further Improving the Market-oriented Green Technology Innovation System.

A substantial body of the literature affirms that carbon trading pilot policies significantly enhance corporate ESG performance [4–7]. With regard to mediating mechanisms, multiple transmission channels have been identified, including the alleviation of financing constraints and a reduction in debt costs [7], the promotion of green technology innovation [8,9], the facilitation of digital transformation and total factor productivity, improvements in energy efficiency [10], and the attraction of government environmental subsidies [11]. Concerning moderating effects, studies have documented that corporate governance quality, institutional investor ownership [5], media attention [12], executives' overseas background [11], customer concentration [4], and carbon market effectiveness and government regulatory intensity all positively moderate the policy's impact. However, heterogeneity analyses yield inconsistent findings across ownership types, industry categories, and regional distributions, suggesting that the boundary conditions of the policy effect merit deeper investigation.

Two notable gaps emerge from this review. First, existing studies have examined moderators such as corporate governance and media coverage in isolation; no research has yet integrated executives' green cognition and environmental policy uncertainty into a unified dual-moderator framework. Although Tian et al. [8] found that managerial green experience positively moderates the carbon trading effect, they did not extend this to ESG performance, while Dai and Jiang [13] linked climate policy uncertainty to ESG outcomes without testing its moderating role in the carbon trading transmission process. Second, while green technology innovation has been preliminarily validated as a mediator, it has not been tested under the joint conditioning of internal cognition and external uncertainty. An integrated "policy–cognition–uncertainty–innovation–ESG" framework thus remains empirically unsupported.

To address these gaps, we treat China's carbon emission trading pilot policy as a quasi-natural experiment. Drawing on panel data of A-share listed firms in high-carbon industries from the Shanghai and Shenzhen stock exchanges over the period 2010–2023, we employ a time-varying difference-in-differences (DID) model to identify the causal effect of carbon

trading on corporate ESG performance, the mediating pathway of green technology innovation, and the dual moderating effects of executives' green cognition and environmental policy uncertainty. Additionally, we conduct heterogeneity analyses across industries and regions.

This study offers three marginal contributions. First, by integrating strategic cognition and institutional uncertainty perspectives, we develop a capability–pressure coupling framework in which executives' green cognition acts as an internal signal-decoding capacity, and environmental policy uncertainty serves as an external signal-amplification mechanism. Their alignment jointly shapes whether carbon trading translates into meaningful ESG gains, advancing beyond the single-moderator approach common in prior work. Second, under this dual-moderator framework, we show that green technology innovation constitutes a statistically significant but economically limited mediating pathway. This finding refines the prevailing "policy–pressure–innovation–ESG" narrative and highlights the need to identify additional transmission channels. Third, heterogeneity results across industries and regions deliver actionable evidence for expanding the national carbon market and tailoring regional regulatory strategies, thus strengthening the practical relevance of market-based instruments for sustainable development.

2. Theoretical Analysis and Research Hypothesis

2.1. Carbon Emission Trading and Corporate ESG Performance

By capping emissions and enabling allowance trading, the carbon emission trading pilot policy internalizes the external cost of carbon into corporate decision-making, thereby driving systematic improvements in environmental management, social responsibility, and governance structures. Dong and Deng [14] show that this policy significantly advances regulated firms' low-carbon transition and thus elevates their overall ESG performance. Hu et al. [15] reveal that, as a market-based instrument, carbon trading effectively stimulates technological innovation and emission-reduction investment—both of which are key pathways to better environmental and governance outcomes. Consistently, Kong et al. [7] report that the policy directly lifts ESG levels among regulated firms, with the effect being more pronounced in certain enterprise types. Based on the above analysis, we propose Hypothesis 1.

H1. *The carbon emission trading pilot policy significantly enhances corporate ESG performance.*

2.2. The Mediating Role of Green Technology Innovation Capability

With the initiation of the carbon emission trading pilot, firms face explicit emission-cost pressures, which create economic incentives for green technology innovation. Wen et al. [6] argue that, to lower compliance costs or to profit from selling surplus allowances, firms tend to increase R&D investment in low-carbon technologies. Zheng et al. [16] found that enhanced green technology innovation capability can reduce resource consumption and pollution emissions, help meet stakeholders' social-responsibility expectations, and facilitate governance optimization, thereby contributing to improved ESG performance. These findings suggest that green technology innovation may serve as one potential transmission channel through which carbon trading policy influences corporate ESG outcomes. However, given that green R&D typically involves substantial time lags, not all green patents translate into meaningful sustainability improvements, and alternative pathways—such as financing constraint alleviation and organizational legitimacy enhancement—may also be operative, we expect this channel to be partial and potentially modest in magnitude. Accordingly, we propose Hypothesis 2:

H2. *Green technology innovation capability partially mediates the relationship between carbon emission trading policy and corporate ESG performance.*

2.3. The Moderating Role of Executives' Green Cognition and Environmental Policy Uncertainty

The joint inclusion of executives' green cognition and environmental policy uncertainty as dual moderators is theoretically grounded in the integration of Upper Echelons Theory (UET) and Institutional Theory. UET posits that organizational outcomes reflect the cognitive frames and interpretive schemas of top managers, who selectively perceive and respond to environmental stimuli; executives' green cognition thus constitutes the internal micro-foundation through which firms decode and prioritize regulatory signals. Institutional Theory, by contrast, emphasizes that firms are embedded in external institutional environments that condition organizational behavior; environmental policy uncertainty, as a manifestation of institutional ambiguity, represents the macro-level contingency that shapes how policy signals are received and interpreted. These two theoretical lenses are complementary: external uncertainty amplifies the intensity of regulatory signals, while internal cognition determines the firm's capacity to translate these signals into ESG-enhancing actions. This integrated approach aligns with recent research that simultaneously examines internal cognitive and external institutional moderators within extended UET and institutional frameworks. Zhang et al. [17] examined the dual moderating roles of business climate and executive green cognition; Ughakpoteni and Meidell [18] developed the concept of "Executive Sustainability Cognition" to explain how executives embed sustainability imperatives when formal institutional guidance is weak or ambiguous; and Gao and Li [19] integrated these theories to examine how top management team characteristics influence persistent green innovation under varying institutional pressures.

Beyond their independent moderating roles, a further theoretical question is whether executives' green cognition and environmental policy uncertainty interact in shaping the carbon trading–ESG relationship. Two competing logics are plausible. The reinforcement logic holds that internal decoding capacity and external amplification pressure are complementary: when policy uncertainty is high, regulatory signals strengthen, and executives with greater green cognition are better positioned to decode and act upon them, yielding a mutually reinforcing effect. The substitution logic, by contrast, posits that the two moderators may partially offset each other: when external pressure is sufficiently intense, it can directly drive ESG action regardless of executives' cognitive orientation, thereby reducing the marginal contribution of green cognition. Which logic prevails is ultimately an empirical question. Accordingly, we not only test the independent moderating effects of EGP and EPU, but also estimate a three-way interaction specification to assess their joint moderating pattern.

2.3.1. Moderating Role of Executives' Green Cognition

Strategic cognition theory holds that executives' perception and interpretation of the external environment directly shape the direction and intensity of corporate strategic responses. In the carbon trading context, He et al. [20] found that executives' green cognition determines whether a firm can accurately identify the emission-reduction pressures and market opportunities embedded in the policy, thereby influencing the depth and breadth of ESG practices. When executives lack sufficient environmental awareness, the firm may respond sluggishly due to internal decision-making inertia, even when the policy sends clear reduction signals. Conversely, executives with higher green cognition are more inclined to proactively convert policy pressures into internal drivers of green transition, motivating concrete actions in environmental governance, social responsibility, and governance

refinement. This strengthens the positive effect of carbon trading on ESG performance. Accordingly, we propose the following:

H3a. *Executives' green cognition positively moderates the relationship between carbon emission trading policy and corporate ESG performance.*

2.3.2. Moderating Role of Environmental Policy Uncertainty

From an uncertainty-theory perspective, fluctuations in the external policy environment shape firms' risk perception and strategic choices. The conventional view holds that policy uncertainty typically suppresses long-term investment; however, we argue that its moderating role may be institution-dependent. China's environmental governance has followed a distinct trajectory of progressive and predictable tightening—from voluntary guidelines to mandatory standards, and from local pilots to national mandates—which fundamentally alters how firms interpret regulatory ambiguity. Within this institutional logic, heightened policy uncertainty is less likely to be perceived as random noise and more likely to be interpreted as a credible prelude to stricter regulation. Drawing on legitimacy theory and signaling theory, we argue that this perception activates a dual mechanism [21,22]. First, policy uncertainty serves as a credible signal of regulatory escalation, prompting firms to pre-emptively strengthen green R&D and ESG management to build compliance capacity ahead of formal mandates. Second, proactive ESG improvement functions as a legitimacy-building strategy that demonstrates compliance commitment to regulators while hedging against future regulatory risks. Through this combined legitimacy-and-signaling mechanism, environmental policy uncertainty may positively—rather than negatively—moderate the carbon trading–ESG relationship. Accordingly, we propose Hypothesis 3b:

H3b. *Environmental policy uncertainty positively moderates the relationship between carbon emission trading policy and corporate ESG performance.*

3. Research Design

3.1. Model Specification

3.1.1. Baseline Regression Model

To identify the causal effect of China's carbon emission trading pilot on corporate ESG performance, we employ a time-varying difference-in-differences (DID) model. This approach is well-suited to our theoretical framework and offers distinctive methodological value within the global emission trading systems literature. Whereas most carbon markets were introduced synchronously across jurisdictions, China's staggered pilot-by-pilot rollout creates a multi-cohort treatment structure that exploits variation in adoption timing to strengthen causal identification and to illuminate how the sequencing of market introduction interacts with regional economic and institutional conditions in shaping firm-level responses. The baseline regression model is specified as follows:

$$Score_{i,t} = \alpha + \beta Policy_{i,t} + \delta Controls_{i,t} + \lambda_i + \rho_t + \varepsilon_{i,t} \quad (1)$$

where $Score_{i,t}$ denotes the ESG performance of firm 'i' in year 't'; $Policy_{i,t}$ is a dummy variable indicating whether firm 'i' is affected by the carbon emission trading policy shock in year 't'; $Controls_{i,t}$ represents the set of control variables; 'i' indexes firms, 't' indexes years; α is the constant term; β is the coefficient of the core explanatory variable, capturing the causal effect of the carbon trading policy on corporate ESG performance; and δ denotes the vector of coefficients for all control variables. To address potential endogeneity concerns, the model incorporates firm fixed effects (λ_i) and year fixed effects (ρ_t); $\varepsilon_{i,t}$ is the random error term.

3.1.2. Mediation Effect Model

To examine whether the carbon emission trading pilot policy affects corporate ESG performance by stimulating firms' green technology innovation capability, following Wen et al. [23], we construct the following model based on the baseline regression model (1):

$$Green_{i,t} = \alpha_0 + \beta_0 Policy_{i,t} + \delta_0 Controls_{i,t} + \lambda_i + \rho_t + \varphi_{i,t} \quad (2)$$

$$Score_{i,t} = \alpha_1 + \beta_1 Policy_{i,t} + \eta_1 Green_{i,t} + \delta_1 Controls_{i,t} + \lambda_i + \rho_t + \varphi_{i,t} \quad (3)$$

In the equation, $Green_{i,t}$ denotes the green technology innovation capability, which is the mediating variable; the definitions of the other variables are identical to those in the baseline regression model specified above.

3.1.3. Moderation Effect Model

To examine the moderating roles of executives' green cognition (EGP) and environmental policy uncertainty (EPU) in the process through which the carbon emission trading policy affects corporate ESG performance, we respectively introduce the interaction terms between the policy variable and the moderator variables and construct the following moderation effect model:

$$Score_{i,t} = \theta + v_0 Policy_{i,t} + v_1 EGP_{i,t} + v_2 Policy_{i,t} \times EGP_{i,t} + \lambda_i + \rho_t + \varphi_{i,t} \quad (4)$$

$$Score_{i,t} = \theta_0 + \sigma_0 Policy_{i,t} + \sigma_1 EGP_{i,t} + \sigma_2 Policy_{i,t} \times EPU_{i,t} + \lambda_i + \rho_t + \varphi_{i,t} \quad (5)$$

where $Policy_{i,t} \times EGP_{i,t}$ and $Policy_{i,t} \times EPU_{i,t}$ are the interaction terms between the policy variable and the moderator variables, respectively. If the coefficients v_2 or σ_2 on the interaction terms are statistically significant, it indicates the presence of the corresponding moderating effects.

3.2. Variable Specification

3.2.1. Dependent Variable

The dependent variable is corporate ESG performance (Score). Following Li et al. [24], in this study, we adopt the comprehensive scores provided by the Huazheng ESG rating system as the measure.

3.2.2. Independent Variable

The core independent variable is the carbon emission trading pilot policy (Policy), defined as a time-varying treatment indicator. It is an interaction term that equals 1 for firms located in pilot regions from the effective year of the policy onward, and 0 otherwise. Because the pilot start dates differ across regions, we follow Guo [25] in determining the policy effective year: if a pilot was launched in July or earlier, it is treated as effective in the current year; if launched after July, it is treated as effective in the subsequent year. The specific implementation dates for each region are reported in Table 1.

Table 1. Policy implementation date.

Time	Region
2013	Shenzhen
2014	Beijing, Tianjin, Shanghai, Hubei, Chongqing, Guangdong
2017	Fujian

3.2.3. Mediating Variable

Green technology innovation capability (Green). Among the green innovation indicators constructed in existing studies, the number of green patent applications or grants is the most mainstream and quantifiable proxy variable [26]. In this study, the ratio of the number of green invention patents independently applied for by the firm in a given year to the total number of invention patents independently applied for in that year is used to measure the firms' green technology innovation capability.

3.2.4. Moderating Variables

Executives' green cognition (EGP): According to upper echelons theory, corporate strategic choices and resource allocation are deeply influenced by the values, cognitive patterns, and past experiences of the top management team. To measure executives' green cognition, we follow the approach of Li et al. [26] by constructing a set of keywords across three dimensions—green competition, social recognition, and perceived environmental pressure—and obtain the measurement results through word-frequency analysis of corporate annual reports.

Environmental policy uncertainty (EPU): Environmental policy uncertainty reflects firms' ambiguous perceptions of the direction, intensity, and sustainability of future environmental regulations. Drawing on the existing analytical framework for measuring economic policy uncertainty, and following the methods of Yang [27] and Wang et al. [28], ten major newspapers, e.g., Beijing Youth Daily and Guangzhou Daily, from the Wisers database are used as the sample. The frequency of keywords such as "environment" and "policy" is counted, the monthly averages over 12 months for each year are calculated, and an annual environmental policy uncertainty index is constructed as follows: EPU = arithmetic mean of monthly economic policy uncertainty indices within the year/100. The variables are detailed in Table 2.

Table 2. Main variable definitions.

Variable Type	Variable Name	Variable Symbol	Variable Definition
Dependent variable	ESG score	Score	Huazheng ESG comprehensive score
Independent variable	Carbon emission trading pilot policy	Policy	Interaction term between pilot regions and pilot years
Mediating variable	Green innovation capability	Green	Number of green invention patents independently applied for in the current year/number of invention patents independently applied for in the current year
Moderating variables	Executives' green cognition	EGP	Frequency of keywords from the dimensions measuring executives' green cognition appearing in the annual reports of listed companies
	Environmental policy uncertainty	EPU	Arithmetic mean of monthly economic policy uncertainty indices within the year/100
Control variables	Leverage ratio	Leverage	Total liabilities at year-end/total assets at year-end
	CEO duality	Dual	Equals 1 if the chairman of the board and the general manager are the same person, and 0 otherwise
	Ownership concentration	Focus	Shareholding ratio of the largest shareholder
	Cash holdings	Cash	(Cash and cash equivalents + trading financial assets)/total assets at period-end
	Growth capability	Grow	Growth rate of operating revenue
	Return on total assets	ROA	Net profit/total assets at year-end
	TobinQ	TobinQ	Market value/total assets
	Firm age	Age	Ln(Firm age + 1)
	Firm size	Size	Ln(Total Assets)

3.2.5. Control Variables

To rule out potential confounding effects from firms' own financial and governance characteristics on ESG performance, and thus, to more accurately identify the net effect of the carbon emission trading policy, following Li et al. [26] and Sun et al. [29], we select the following control variables: leverage ratio (Leverage), CEO duality (Dual), ownership concentration (Focus), cash holdings (Cash), growth capability (Grow), return on total assets (ROA), TobinQ, Firm age (Age), and Firm size (Size).

3.3. Data Sources

To identify the causal effect, we construct a panel of A-share listed firms in 16 high-carbon industries on the Shanghai and Shenzhen stock exchanges from 2010 to 2023. This period spans the pre-pilot baseline (2010), staggered pilot launches (from 2013), the "dual carbon" goal announcement (2020), and the national carbon market launch (2021), providing a clean pre-treatment window for DID estimation. The sample starts in 2010 because domestic ESG ratings and green patent data become consistently available from that year onward. Following Lu [30], we identify high-carbon industries by computing each industry's relative carbon emission intensity ratio and retain those with a ratio greater than 1. The resulting 16 sectors—Coal Mining and Washing (02), Extraction of Petroleum and Natural Gas (03), Manufacture of Paper and Paper Products (16), Petroleum Processing, Coking and Nuclear Fuel Processing (19), Manufacture of Raw Chemical Materials and Chemical Products (20), Manufacture of Chemical Fibers (22), Manufacture of Rubber Products (23), Manufacture of Plastic Products (24), Manufacture of Non-metallic Mineral Products (25), Smelting and Rolling of Ferrous Metals (26), Manufacture of Metal Products (28), Manufacture of General-purpose Equipment (29), Manufacture of Special-purpose Equipment (30), Production and Supply of Gas (38), Construction (40), and Transport, Storage, Postal and Telecommunication Services (41)—are all non-power industries and thus remained subject only to regional pilot regulations throughout the observation period. The financial and governance data are from CSMAR; the green patent data are from CNRDS. We exclude ST, *ST, and financially abnormal firms; drop observations with missing key variables; and winsorize all continuous variables at the 1st and 99th percentiles. The final sample consists of 11,241 valid observations.

4. Empirical Results

4.1. Descriptive Statistics

Table 3 reports the descriptive statistics of the main variables. The dependent variable, corporate ESG performance (Score), ranges from 60.30 to 83.73, with a mean of 73.3806, revealing substantial cross-sectional variation in ESG outcomes. The policy shock indicator (Policy) has a mean of 0.2762, indicating that approximately 27.6% of the sample observations are exposed to the carbon emission trading pilot. The mediating variable, green technology innovation capability (Green), exhibits a mean of 0.0470 and a maximum of 0.9821, reflecting a relatively low average level but pronounced differentiation across firms. Turning to the moderating variables, executives' green cognition (EGP) displays a mean of 4.5081 with a standard deviation of 4.9963 and a range from 0 to 22, highlighting marked disparities in green awareness among executives. Environmental policy uncertainty (EPU) has a mean of 4.7539 and a standard deviation of 2.3740, indicating notable fluctuations over the sample period. The remaining control variables—including leverage, cash holdings, profitability, ownership concentration, Tobin's Q, growth capability, and CEO duality—all lie within economically reasonable ranges and are broadly consistent with prior studies.

Table 3. Descriptive statistical analysis.

Variable	Mean	Std. Dev.	Min	Median	Max
Score	73.3806	4.3457	60.3000	73.2600	83.7300
Policy	0.2762	0.4471	0.0000	0.0000	1.0000
Green	0.0470	0.1508	0.0000	0.0000	0.9821
EGP	4.5081	4.9963	0.0000	3.0000	22.0000
EPU	4.7539	2.3740	0.9889	5.0889	7.9187
Leverage	0.4119	0.1929	0.0603	0.4094	0.8525
Cash	0.1974	0.1389	0.0215	0.1578	0.6791
ROA	0.0440	0.0479	−0.1304	0.0401	0.1909
Focus	35.6282	14.8640	9.1500	33.7700	76.5300
TobinQ	1.7584	0.9551	0.8146	1.4566	6.3172
Grow	0.1546	0.3123	−0.4460	0.1031	1.6571
Dual	0.2855	0.4517	0.0000	0.0000	1.0000
Age	1.9407	0.9208	0.0000	2.0794	3.4673
Size	22.3420	1.3905	20.1712	22.0741	26.8076

4.2. Baseline Regressions

Table 4 reports the baseline regression results of the policy effect on corporate ESG performance (Score). Models 1 through 5 sequentially incorporate year fixed effects, firm fixed effects, and control variables. The coefficient of the core variable Policy is significantly positive across all models. In the most stringently controlled Model 5, the coefficient of Policy is 0.8073 and is significant at the 1% level, indicating that the pilot policy significantly improves the ESG performance of firms in the treatment group, thus supporting Hypothesis 1. In economic terms, the policy increases the average Score by approximately 0.81 points, which corresponds to an increase of about 1.11% relative to the sample mean of 73.26, suggesting a certain degree of economic significance. Moreover, comparing Model 1 (0.4411) with Model 3 (0.6935) reveals that omitting firm fixed effects would underestimate the policy effect, and as control variables are gradually added, the estimated coefficients stabilize in the range of 0.8 to 0.9, indicating that the conclusion is robust.

Table 4. Baseline regression results.

	(1) Score	(2) Score	(3) Score	(4) Score	(5) Score
Policy	0.4411 ***	0.3980 **	0.6935 ***	0.8720 ***	0.8073 ***
	(0.0916)	(0.1959)	(0.2501)	(0.2845)	(0.2643)
Leverage					−2.8043 ***
					(0.6121)
Dual					−0.1281
					(0.1698)
Focus					0.0008
					(0.0098)
Cash					−0.8769
					(0.5615)
Grow					−0.5021 ***
					(0.1329)
ROA					3.0385 **
					(1.4517)
TobinQ					−0.0614
					(0.0665)
Size					0.9788 ***
					(0.1563)

Table 4. *Cont.*

	(1) Score	(2) Score	(3) Score	(4) Score	(5) Score
Age					−1.7958 ***
					(0.1687)
Constant	73.2587 ***	73.2706 ***	73.1890 ***	73.1397 ***	56.1611 ***
	(0.0481)	(0.1050)	(0.0691)	(0.0786)	(3.3985)
Year FE	No	Yes	No	Yes	Yes
Firm FE	No	No	Yes	Yes	Yes
N	11,241	11,241	11,241	11,241	11,241
Adj. R^2	0.0020	0.0236	0.3803	0.4034	0.4290

Note: ** $p < 0.05$, *** $p < 0.01$; standard errors in parentheses.

4.3. Mediation Effects

4.3.1. Traditional Stepwise Regression Approach

To examine the mediating role of green technology innovation in the impact of the carbon emission trading policy on corporate ESG performance, we employ the three-step procedure proposed by Wen et al. [21] for stepwise regression, with the results presented in Table 5. In column (1), the coefficient of the core explanatory variable Policy is 0.8073 ($p < 0.01$), indicating that the carbon emission trading pilot policy significantly enhances corporate ESG performance; thus, the total effect is established. In column (2), with green innovation (Green) as the dependent variable, the coefficient of Policy is 0.0178 ($p < 0.01$), suggesting that the carbon trading policy significantly stimulates green innovation activities of firms in the pilot regions—that is, the policy effectively promotes R&D investment and patent output in the green technology domain. In column (3), when both the policy variable and the mediating variable are included in the model, the coefficient of Green is 0.7662 ($p < 0.01$), and the coefficient of Policy declines from 0.8073 to 0.7937 ($p < 0.01$), indicating that firms' green technology innovation capability plays a partial mediating role between the carbon trading policy and ESG performance. These results suggest that, by internalizing the external cost of carbon emissions, the carbon emission trading policy alters the relative factor prices and cost–benefit structure facing firms, prompting them to adopt green innovation capability as a core strategic instrument for achieving emission reduction targets, thereby enhancing their overall ESG performance. Accordingly, Hypothesis 2 is validated.

Table 5. Mediation effect test results.

	(1) Score	(2) Green	(3) Score
Policy	0.8073 ***	0.0178 **	0.7937 ***
	(0.2643)	(0.0069)	(0.2641)
Green			0.7662 ***
			(0.2675)
Constant	56.1611 ***	−0.0979	56.2362 ***
	(3.3985)	(0.1063)	(3.3843)
Control Variables	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
N	11,241	11,241	11,241
Adj. R^2	0.4290	0.3157	0.4294

Note: ** $p < 0.05$, *** $p < 0.01$; standard errors in parentheses.

4.3.2. Bootstrap Mediation Test

To further verify the robustness of the mediation effect identified via the stepwise approach, we employ the Bootstrap method with 1000 replications and report bias-corrected confidence intervals. The results are presented in Table 6.

Table 6. Bootstrap mediation test results.

	Observed Coefficient	Bootstrap Std. Err.	Bias-Corrected 95% CI	
			Lower	Upper
Indirect effect	0.0136	0.0066	0.0035	0.0288
Path a (Policy → Green)	0.0178	0.0056	0.0074	0.0299
Path b (Green → ESG)	0.7662	0.2777	0.1796	1.2819

The bias-corrected 95% confidence interval for the indirect effect of green technology innovation is [0.0035, 0.0288], which excludes zero, confirming a statistically significant indirect pathway. Specifically, the path from carbon trading policy to green technology innovation (coefficient a = 0.0178, bias-corrected 95% CI [0.0074, 0.0299]) and the path from green technology innovation to ESG performance (coefficient b = 0.7662, bias-corrected 95% CI [0.1796, 1.2819]) are both significant. These results corroborate that green technology innovation serves as a partial mediator between carbon emission trading policy and corporate ESG performance, providing additional support for Hypothesis 2.

4.4. Testing the Parallel Trend Assumption

The results of the parallel trend test are presented in Figure 1. In the pre-policy periods (from period -5 to period -1), the estimated treatment effect coefficients all fluctuate around zero, and their 95% confidence intervals all contain zero, indicating that there were no systematic pre-existing differences in ESG performance between the treatment group and the control group. This satisfies the parallel trends assumption and provides valid support for the causal identification of the difference-in-differences model. From the current period of policy implementation (period 0) onward, the treatment effect coefficients show an upward trend but are not significant in the initial stage. From the first year after implementation (period 1) onward, the coefficients turn positive and continue to increase, with the confidence intervals gradually moving away from the zero line, indicating that the policy effect emerges progressively. By the fifth year (period 5), the coefficient reaches a relatively high level and becomes statistically significant.

The above dynamic trend suggests that the enhancing effect of the carbon emission trading pilot policy on corporate ESG performance exhibits a gradual pattern: in the initial stage, firms need to make strategic adjustments and resource reallocation; subsequently, emission reduction pressures are gradually internalized as drivers of green transition, and the policy effect continues to strengthen over time. In summary, the parallel trend test supports the validity of the difference-in-differences model, reveals the dynamic evolution of the policy effect, and reinforces the robustness of the baseline regression conclusions.

4.5. Placebo Test Results

The placebo test results are shown in Figure 2, which presents the kernel density distribution of the estimated coefficients from 500 random sampling iterations and the corresponding distribution of *p*-values. As can be seen from the figure, the regression coefficients are normally distributed around zero, and the actual coefficient far exceeds the range of the simulated distribution, indicating that there is no placebo effect.

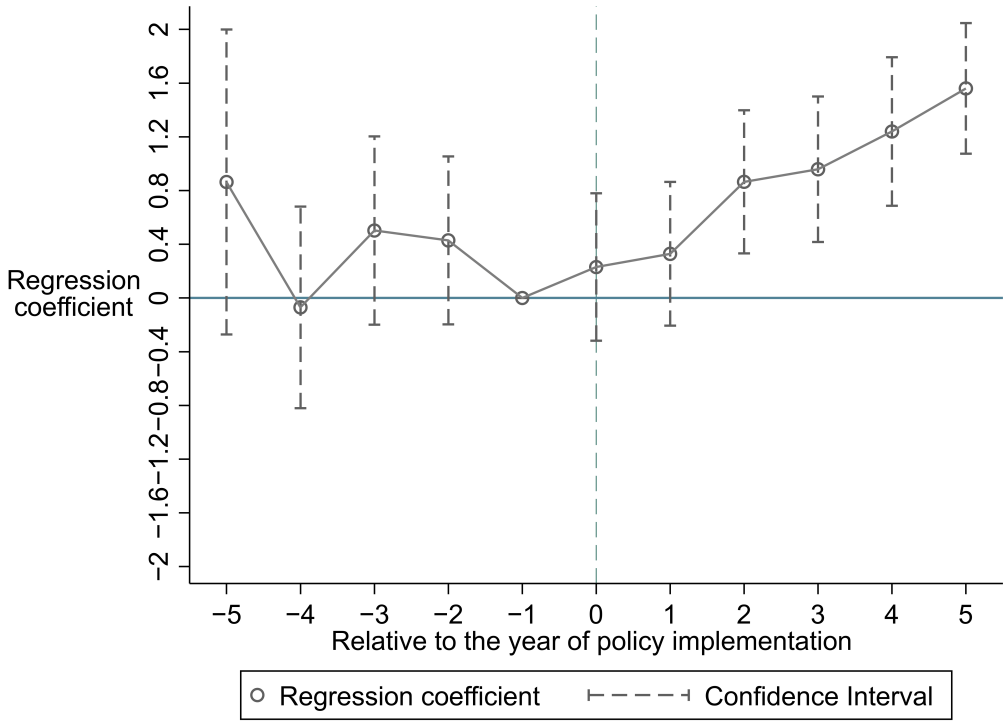

Figure 1. Parallel trend test.

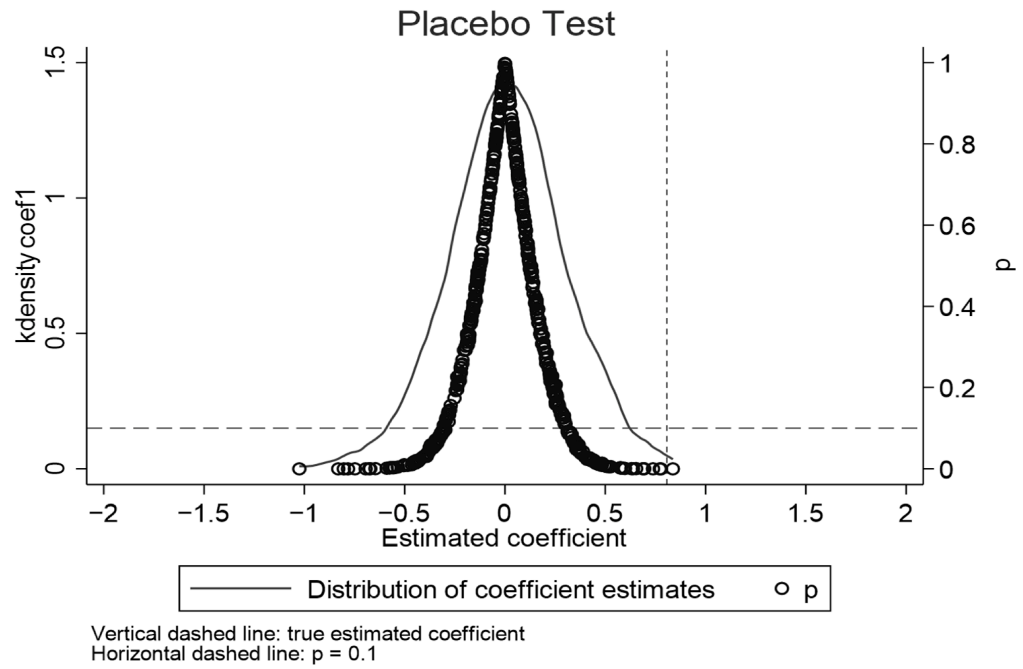

Figure 2. Placebo test.

4.6. Robustness Checks

To ensure the reliability of the baseline findings, we conduct a series of robustness checks addressing potential endogeneity, measurement bias, and rating methodology discontinuity. The results are presented in Table 7.

Table 7. Robustness check results.

	(1) Score	(2) Score1	(3) Score	(4) Score1
Policy	0.6729 **	0.0349 ***	0.7851 ***	0.0335 ***
	(0.2896)	(0.1239)	(0.2726)	(0.1268)
Constant	60.4203 ***	2.5182 ***	57.6136 ***	2.5043 ***
	(3.8361)	(0.1568)	(3.7758)	(0.1632)
Control Variables	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
N	9512	11,241	7876	10,381
Adj. R^2	0.4531	0.6556	0.4356	0.6565

Note: ** $p < 0.05$, *** $p < 0.01$; standard errors in parentheses.

4.6.1. Lagged Control Variables

Considering the possible lagged effects of the policy and potential reverse causality concerns, Column (1) re-estimates the model by lagging all control variables by one period. The results show that the coefficient of the core explanatory variable Policy is 0.6729 and remains significantly positive at the 5% level, consistent with the baseline regression conclusion. This indicates that the enhancing effect of the carbon emission trading pilot policy on corporate ESG performance is persistent and does not dissipate over time.

4.6.2. Replacement of the Dependent Variable

To avoid the possibility that our findings are driven by the specific ESG measurement approach, Column (2) employs the CnRDS ESG score (Score1) as an alternative dependent variable. The Policy coefficient remains positive and highly significant at the 1% level (0.0349, $p < 0.01$), confirming that the baseline result is robust to alternative ESG rating systems.

4.6.3. Addressing the 2018 Huazheng Rating Methodology Revision

In 2018, Huazheng significantly revised its ESG rating methodology, introducing more granular industry weighting and a negative-list mechanism. To ensure that this methodological break does not confound our causal identification, we conduct two additional tests. First, Column (3) completely excludes the 2018 observations and re-estimates the baseline model. The Policy coefficient is 0.7851 and remains highly significant at the 1% level ($p < 0.01$). Second, Column (4) further combines this sample restriction with the alternative ESG measure (Score1) over the full period. The Policy coefficient is 0.0335, which is also significant at the 1% level ($p < 0.01$). Both specifications confirm that the 2018 methodology revision does not pose a substantive threat to our causal identification.

In summary, all four robustness checks consistently demonstrate that the carbon emission trading pilot policy significantly improves the ESG performance of firms in the treatment group, and this core conclusion remains robust and reliable across alternative specifications, variable definitions, and sample adjustments.

4.7. Moderation Effects

To examine the moderating roles of executives' green cognition (EGP) and environmental policy uncertainty (EPU) in the carbon trading–ESG relationship, we augment the baseline model with the interaction terms Policy × EGP and Policy × EPU. To further assess whether the two moderators operate independently, we estimate a combined specification that includes both interaction terms simultaneously. Table 8 reports the results, with Columns (1) through (3) presenting the respective estimates.

Table 8. Moderation effect results.

	(1) Score	(2) Score	(3) Score	(4) Score
Policy	0.5464 **	0.2182	0.0880	−0.1630
	(0.2154)	(0.2588)	(0.2689)	(0.3054)
EGP	−0.0134		−0.0100	−0.0066
	(0.0129)		(0.0130)	(0.0214)
Policy × EGP	0.0539 **		0.0407 *	0.1180 **
	(0.0223)		(0.0228)	(0.0484)
EPU		0.0000	0.0000	0.0000
		(.)	(.)	(.)
Policy × EPU		0.1233 ***	0.1093 ***	0.1575 ***
		(0.0376)	(0.0384)	(0.0493)
EGP × EPU				−0.0006
				(0.0037)
Policy × EGP × EPU				−0.0137 *
				(0.0080)
Constant	56.2675 ***	56.0400 ***	56.1344 ***	56.0939 ***
	(2.3587)	(2.3570)	(2.3583)	(2.3589)
Control Variables	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
N	11,241	11,241	11,241	11,241
Adj. R^2	0.4292	0.4296	0.4296	0.4297

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

Column (1) shows that the coefficient of Policy × EGP is 0.0539 and significant at the 5% level, indicating that executives' green cognition positively moderates the policy effect: the higher the level of green cognition among the top management team, the stronger the ESG-enhancing effect of carbon trading. Hypothesis 3a is thus supported.

Column (2) reports the moderating effect of environmental policy uncertainty. The coefficient of Policy × EPU is 0.1233 and significant at the 1% level. Because EPU is a macro-level annual index perfectly collinear with year fixed effects, its main effect is automatically absorbed in the fixed-effects estimation—a standard econometric treatment that does not affect the unbiased estimation of the interaction term. This result indicates that environmental policy uncertainty positively moderates the policy effect: when facing higher policy uncertainty, firms tend to proactively strengthen their ESG practices to hedge against future regulatory risks, thereby amplifying the carbon trading effect. Hypothesis 3b is thus supported.

Column (3) includes both interaction terms simultaneously. The coefficient of Policy × EGP is 0.0407 and significant at the 10% level ($p < 0.1$), while that of Policy × EPU is 0.1093 and significant at the 1% level ($p < 0.01$). Both remain significantly positive, confirming that executives' green cognition and environmental policy uncertainty exert independent positive moderating effects even when mutually controlled. This finding not only reinforces Hypotheses H3a and H3b, but also suggests that internal signal-decoding capacity and external signal-amplification pressure function as complementary yet distinct reinforcing mechanisms in the carbon trading–ESG transmission pathway.

Column (4) further incorporates the three-way interaction term Policy × EGP × EPU. The two-way interactions Policy × EGP (coefficient = 0.1180, $p < 0.05$) and Policy × EPU (coefficient = 0.1575, $p < 0.01$) remain significantly positive, while the three-way interaction is negative and marginally significant (−0.0137, $p < 0.1$). This negative coefficient suggests a partial substitution effect at elevated levels: when environmental policy uncertainty is already high, the marginal contribution of executives' green cognition to the policy

effect is attenuated. This pattern refines the capability–pressure coupling framework by revealing a boundary condition—while the two moderators operate as complementary mechanisms at moderate levels, their effects exhibit diminishing marginal returns when both are simultaneously high, likely due to functional overlap in driving ESG action.

4.8. Heterogeneity Analysis

Considering that the effect of the carbon emission trading policy may vary across industry pollution attributes and regional development levels, we conduct heterogeneity analyses from two dimensions: industry pollution degree and regional distribution. The results are presented in Tables 9 and 10.

Table 9. Pollution level.

	(1) Score High Pollution	(2) Score Low Pollution
Policy	2.3238 ***	0.0063
	(0.3063)	(0.2378)
Constant	57.5803 ***	52.9343 ***
	(3.5225)	(3.2837)
Control Variables	Yes	Yes
Year FE	Yes	Yes
Firm FE	Yes	Yes
N	5169	6072
Adj. R^2	0.4393	0.4547

Note: *** $p < 0.01$; standard errors in parentheses.

Table 10. Location of the enterprise.

	(1) Score Eastern Region	(2) Score Central Region	(3) Score Western Region
Policy	0.6781 ***	1.0799 *	0.7763
	(0.2076)	(0.6058)	(1.4975)
Constant	53.4210 ***	55.5090 ***	50.7626 ***
	(2.9947)	(5.8553)	(6.6610)
Control Variables	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
N	8026	1910	1305
Adj. R^2	0.4467	0.3400	0.4356

Note: * $p < 0.1$, *** $p < 0.01$; standard errors in parentheses.

4.8.1. Industry Heterogeneity: High-Pollution vs. Low-Pollution

Columns (1) and (2) in Table 9 report the regression results for the sub-samples of high-pollution and low-pollution firms, respectively. In the high-pollution firm group, the coefficient of Policy is 2.3238 and is significantly positive at the 1% level, whereas in the low-pollution firm group, the coefficient of Policy is 0.0063 and fails to pass the significance test. This result indicates that the enhancing effect of the carbon emission trading pilot policy on corporate ESG performance is mainly concentrated in high-pollution industries, with a limited impact on low-pollution industries. The reason lies in the fact that high-pollution industries have high energy consumption intensity and large emission volumes, facing stronger compliance pressures, which prompts firms to proactively increase environmental investment and technological upgrades, thereby improving ESG performance more significantly.

4.8.2. Regional Heterogeneity: Eastern, Central, and Western Regions

Table 10 presents the regression results for the regional sub-samples. In the eastern region, the coefficient of Policy is 0.6781 ($p < 0.01$); in the western region, the coefficient is 0.7763 but not significant; and the policy effect is strongest in the central region, with a coefficient of 1.0799 ($p < 0.1$). These results indicate that the carbon trading policy significantly improves ESG performance for firms in the eastern and central regions, whereas its effect on firms in the western region is not significant. The possible reasons are as follows: the eastern region has a higher degree of marketization, abundant financial resources, and higher efficiency in green technology commercialization, and also launched the carbon trading pilots earliest among the provincial-level regions, with stronger policy enforcement; the central region, given its urgent need for industrial structure transformation, may exhibit a more pronounced marginal policy effect; and the western region, constrained by its stage of economic development, reliance on resource-based industries, and insufficient supply of green finance, faces relatively limited policy transmission efficiency.

5. Conclusions and Policy Implications

5.1. Conclusions and Discussion

Using panel data of A-share listed firms in high-carbon industries (2010–2023), we confirm that China's carbon emission trading pilot significantly improves corporate ESG performance (coefficient = 0.8073, $p < 0.01$), consistent with prior evidence [31–33]. Beyond this confirmation, several findings merit critical discussion.

Weak innovation channel. The carbon emission trading pilot is expected to incentivize firms to develop green technologies, upgrade production processes, and improve resource efficiency, thereby enhancing ESG performance—a logic consistent with prior studies suggesting that environmental policies stimulate green innovation in heavily polluting firms [32,34]. Our empirical results, however, reveal that this channel is considerably weaker than commonly assumed. Green technology innovation exerts a statistically significant but economically modest mediating effect (indirect effect = 0.0136, $p < 0.01$), explaining only 1.68% of the total policy effect. This limited mediating capacity likely reflects the inherent time lags of green R&D, the predominance of incremental over substantive patents, and firms' reliance on process optimization rather than patentable breakthroughs. This finding is theoretically consistent with the "capability–environment fit" framework proposed by Mao and Li (2026) [35], who demonstrate that green innovation resources do not automatically translate into performance gains; rather, their effectiveness critically depends on the synergy between external regional innovation capacity and internal corporate R&D capability. In our policy context, the carbon trading pilot succeeds in generating a surge in green patent applications, but the weak mediating effect suggests that these patents are often of limited quality or merely strategic responses, lacking the transformative power to upgrade comprehensive ESG ratings without sufficient internal decoding capacity and clear external institutional signals.

To further probe this weak aggregate effect, we disaggregated green patents into green invention patents (substantive innovation) and green utility model patents (incremental improvement) and conducted separate mediation tests. The results reveal a marked divergence: the carbon emission trading pilot policy significantly promotes green invention patent applications (coefficient = 0.0178, $p < 0.01$), and these patents positively mediate ESG performance. In stark contrast, the policy exerts a significant negative effect on green utility model patent applications (coefficient = -0.0638, $p < 0.05$), and these patents do not serve as a positive mediator—when included, the direct policy coefficient rises from 0.8073 to 0.8341, indicating a suppression effect. This internal offset, whereby the positive mediation

of substantive innovation is partially canceled by the negative response of incremental innovation, explains why the overall mediating effect is economically modest.

Given the limited role of the innovation channel, we further explored two alternative transmission pathways. Using the SA index as a proxy for financing constraints and the CSMAR Carbon Disclosure Index (CDIndex) for carbon disclosure quality, supplementary mediation tests were conducted. The results show that both alternative channels substantially exceed the innovation pathway: the indirect effect via financing constraints is 0.1294, accounting for 15.99% of the total policy effect, and that via carbon disclosure quality is 0.0656, accounting for 8.10%. In comparison, the innovation channel's indirect effect of 0.0136 (1.68%) is approximately 9.5 times smaller than the financing channel and 4.8 times smaller than the disclosure channel. These findings indicate that information-based and financing-based mechanisms are the primary transmission channels through which carbon trading enhances ESG performance, while the innovation pathway, though statistically significant, plays a relatively minor role.

Taken together, the combined evidence—internal offset within patent types and external substitution by alternative channels—reinforces the necessity of our dual-moderation framework. As Mao and Li (2026) [35] caution, innovation output alone is an insufficient transmission mechanism; only when firms possess strong internal signal-decoding capacity (i.e., executives' green cognition) and operate under clear external institutional signals (i.e., environmental policy uncertainty) can green innovation resources be effectively converted into substantive ESG improvements. Our findings thus not only confirm the policy's direct effect but also echo this caveat, validating the capability–pressure coupling logic that lies at the heart of our theoretical framework.

Capability–pressure coupling: Executives' green cognition (interaction coefficient = 0.0539, $p < 0.05$) and environmental policy uncertainty (interaction coefficient = 0.1233, $p < 0.01$) both positively moderate the policy–ESG link. We interpret this through a capability–pressure coupling logic: internal signal-decoding capacity and external signal-amplification pressure function as complementary conditions. This extends prior single-moderator studies by demonstrating that the two factors, when examined together, exhibit mutually reinforcing effects. At the same time, the three-way interaction result reveals a boundary condition: when both moderators are simultaneously high, this complementarity exhibits diminishing marginal returns, indicating a partial substitution at elevated levels. This dynamic pattern enriches the capability–pressure coupling logic by specifying the conditions under which the complementary relationship holds most strongly.

The uncertainty puzzle: The positive moderating role of policy uncertainty contrasts with developed-economy evidence, where uncertainty typically suppresses environmental investment [36]. We attribute this divergence to China's distinct institutional trajectory of progressive regulatory tightening, which leads firms to interpret heightened uncertainty as a credible prelude to stricter regulation rather than random noise. This interpretation aligns with emerging-market evidence and institutional adaptation theory, but remains tentative; systematic cross-country research is needed to establish its boundary conditions.

Heterogeneous effects. Heavily polluting firms (coefficient = 2.3238, $p < 0.01$) and firms in eastern (coefficient = 0.6781, $p < 0.01$) and central (coefficient = 1.0799, $p < 0.1$) regions benefit disproportionately, reflecting differential regulatory exposure and regional disparities in institutional capacity. These patterns imply that uniform carbon pricing may yield uneven outcomes without complementary measures for less-developed regions.

5.2. Policy Implications

5.2.1. Policy-Level Implications

First, we should accelerate the phased expansion of the national carbon market. Our findings confirm that carbon trading significantly improves ESG performance, yet the effect remains concentrated in pilot regions and industries. Given that the eight key sectors account for approximately 75% of national emissions, a binding timeline should be established for incorporating steel, building materials, and chemicals, thereby extending the market's scale effect to a broader set of high-carbon industries.

Second, we should recalibrate green innovation incentives while strengthening complementary transmission channels. Our results show that green technology innovation explains only a modest fraction of the total policy effect. While innovation support retains its relevance, policymakers should avoid over-reliance on this single channel. A portion of allowance auction revenues could be directed toward green R&D subsidies, while parallel efforts—such as green credit guarantee mechanisms and standardized carbon disclosure frameworks—should be developed to reinforce the financing and legitimacy pathways identified in our mechanism analysis.

Third, we should adopt regionally differentiated carbon market rules. Our heterogeneity results reveal significant policy effects in the eastern and central regions but not in the western region. Accordingly, western regions could be granted transitional compliance flexibility, coupled with targeted green technology transfer and capacity-building support. Simultaneously, enhanced inter-regional coordination—through mutual allowance recognition and information sharing—would help prevent carbon leakage and promote equitable outcomes.

5.2.2. Firm-Level Implications

First, we should embed carbon asset management into corporate strategy, particularly for heavily polluting firms. Our findings indicate that compliance pressure can serve as a catalyst for technological and managerial upgrading. Firms should establish dedicated carbon management functions to monitor emission gaps and allowance positions, and plan proactively for low-carbon retrofitting. Linking executive compensation to ESG performance can further align managerial incentives with sustainability goals.

Second, we should institutionalize executives' green cognition development. Our moderation analysis confirms that green cognition amplifies the policy effect on ESG. Firms can strengthen this internal capability by establishing board-level environmental committees, incorporating environmental expertise into director nomination criteria, and delivering systematic ESG training for senior management—thereby reducing reliance on individual executives' personal environmental values.

Third, we should treat policy uncertainty as a strategic opportunity rather than a deterrent. Contrary to the conventional view, our findings suggest that, in China's progressive regulatory context, heightened uncertainty can motivate pre-emptive ESG strengthening. Firms should proactively monitor policy signals, enhance carbon disclosure, and build stakeholder trust during periods of uncertainty, thereby securing first-mover advantages when regulatory tightening materializes.

5.3. Limitations and Future Research

Several limitations warrant attention and suggest directions for future work. First, the sample is restricted to A-share listed firms in high-carbon industries, which may constrain generalizability. Extending the analysis to non-listed firms, SMEs, or other emerging economies would test external validity. Second, ESG performance is proxied by Huazheng ratings and executives' green cognition is text-based, both of which are susceptible to

measurement bias. Future studies could adopt multi-source ESG data and survey-based cognition measures to strengthen construct validity. Third, the quasi-experimental DID design cannot fully rule out endogeneity from non-random pilot selection. As the national carbon market matures and granular emission data become accessible, stronger identification strategies (e.g., IV, RDD) should be exploited to reinforce causal inference. Fourth, the sole mediator examined is green technology innovation; alternative channels—including supply chain pressure, human capital upgrading, and consumer awareness—deserve systematic investigation. Finally, the sample period ends in 2023, capturing only the early national-market stage. Long-term dynamic effects and policy interactions (e.g., with carbon taxes or renewable portfolio standards) offer promising avenues for future inquiry.

Author Contributions: Conceptualization, G.M.; data curation, L.X.; formal analysis, L.X.; writing—original draft, L.X.; writing—review and editing, G.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Xiao, Q.; Yin, J.D. The Impact of ESG Information Disclosure of Heavily Polluting Enterprises on Financing Constraints: Based on the ESG Risk Masking Effect. *Sci. Technol. Econ.* **2026**, *39*, 86–90. [CrossRef]
2. Wei, J.; Hu, R.; Chen, F. The Path to Sustainable Stability: Can ESG Investing Mitigate the Spillover Effects of Risk in China's Financial Markets? *Sustainability* **2024**, *16*, 10316. [CrossRef]
3. Wan, X.; Yang, M.; Liang, J.; Cao, J.; Wang, Z.; Ren, K. When Does ESG Performance Pay Off? Corporate Reputation and Firm Performance in Chinese State-Owned Enterprises. *Sustainability* **2026**, *18*, 4975. [CrossRef]
4. Chen, X.; Zou, K.; Gan, X.; Hu, Y. Carbon Emission Trading Pilot Policy and Corporate ESG Performance: Evidence from a Quasi-Natural Experiment in China. *SAGE Open* **2025**, *15*, 17. [CrossRef]
5. Xu, H.; Yang, R. Does Carbon Market Improve ESG Performance? Evidence from China. *J. Clean. Prod.* **2025**, *514*, 145810. [CrossRef]
6. Wen, H.Y.; Du, J.Y.; Gao, H.Y.; Li, X.M. Corporate ESG Performance under the Incentive of Carbon Market: Empirical Evidence from China's Carbon Emission Trading Pilot. *J. Financ. Res.* **2024**, *532*, 95–112.
7. Kong, X.X.; Zhang, X.X.; Tang, X.M. The Impact of the Carbon Emission Trading Pilot Policy on Corporate ESG Performance. *Stat. Decis.* **2024**, *40*, 174–178. [CrossRef]
8. Tian, B.; Yu, J.; Tian, Z. The impact of market-based environmental regulation on corporate ESG performance: A quasi-natural experiment based on China's carbon emission trading scheme. *Heliyon* **2024**, *10*, e26687. [CrossRef] [PubMed]
9. Xie, B.; Cheng, D.P. Can Market-Based Environmental Regulation Promote Corporate ESG Practices? A Quasi-Natural Experiment Based on the Carbon Emission Trading Pilot Policy. *Ecol. Econ.* **2024**, *40*, 161–168.
10. Huang, C.; Yang, S.Y.; Liu, J.Q.; Chen, Y. Carbon Emission Trading Policy, Energy Efficiency, and ESG Performance. *Coop. Econ. Sci. Technol.* **2025**, *21*, 18–21. [CrossRef]
11. Chen, Y.Q.; Li, M.Y. Can the Carbon Emission Trading System Induce Better Corporate ESG Performance? *Coal Econ. Res.* **2024**, *44*, 46–55. [CrossRef]
12. Li, C.X.; Song, Q.F. Research on the Impact of Carbon Emission Trading Pilot Policy on Corporate ESG Performance. *J. Xi'an Shiyou Univ.* **2025**, *34*, 37–48, 106. [CrossRef] [PubMed]
13. Dai, Z.; Jiang, Q. Climate policy uncertainty and corporate ESG performance: Evidence from Chinese listed companies. *China Financ. Rev. Int.* **2025**, *15*, 578–607. [CrossRef]
14. Dong, K.Y.; Deng, Y.Y. The Impact of Carbon Emission Trading Pilot Policy on Corporate Low-Carbon Transition. *Financ. Econ. Issues Res.* **2023**, *12*, 52–63.

15. Hu, J.; Huang, N.; Shen, H.T. Can Market-Based Environmental Regulation Promote Firm Technological Innovation? A Natural Experiment Based on China's Carbon Emission Trading Mechanism. *J. Financ. Res.* **2020**, *475*, 171–189.
16. Zheng, Y.Z.; Wang, Z.H.; Cai, Y.; Xie, R.X.; Men, C.H. The Impact of Corporate Green Technology Innovation on ESG Performance under the New "Dual Carbon" Pattern and Its Pathways. *J. Technol. Econ.* **2023**, *42*, 64–77.
17. Zhang, W.; Yu, D.; Peng, S.; Zhang, D. Unveiling the ESG performance and green innovation: The moderating roles of business climate and executive green cognition. *J. Clean. Prod.* **2026**, *563*, 148447. [CrossRef]
18. Ughakpoteni, P.O.; Meidell, J.E. Closing the ESG Implementation Gap in Emerging Markets: Executive Sustainability Cognition as Cognitive Governance. *Sustainability* **2026**, *18*, 1605. [CrossRef]
19. Gao, D.; Li, S. Top management team biographical similarity and persistent green innovation: Evidence from Chinese listed companies. *Res. Int. Bus. Financ.* **2025**, *77*, 103001. [CrossRef]
20. He, S.C.; Huang, X.; Chen, Q. Can Managers' Environmental Cognition Improve Corporate Performance? The Mediating Role of Proactive Environmental Strategy and the Moderating Role of Business Environment Uncertainty. *Nankai Bus. Rev.* **2016**, *19*, 49–57.
21. Zhang, D.Y. How Do Environmental Policies Affect Upgrading of Chinese Enterprises? A Quasi-Natural Experiment Based on the "Two Control Zones" Policy. *Ind. Econ. Res.* **2020**, 73–85.
22. Wang, H.; Sun, H.; Xiao, H.Y.; Xin, L. Relationship between Environmental Policy Uncertainty, Two-Way FDI and Low-Carbon TFP. *China Popul. Resour. Environ.* **2020**, *30*, 75–86.
23. Wen, Z.L.; Ye, B.J. Mediation Effect Analysis: Methods and Model Development. *Adv. Psychol. Sci.* **2014**, *22*, 731–745. [CrossRef]
24. Li, Z.F.; Chen, J.Y. Corporate ESG Performance and Short-Term Debt for Long-Term Use. *J. Quant. Technol. Econ.* **2023**, *40*, 152–171. [CrossRef]
25. Guo, J.J.; Fang, Y.; Yang, Y. Does the Reform of Sewage Charge Collection Standard Promote Industrial Sulfur Dioxide Emission Reduction in China? *J. World Econ.* **2019**, *42*, 121–144. [CrossRef]
26. Li, Y.B.; Xia, Y.; Zhao, Z. The Impact of Executives' Green Cognition on the Performance of Heavily Polluting Firms: A Moderated Mediation Model. *Sci. Technol. Prog. Policy* **2023**, *40*, 113–123. [CrossRef]
27. Yang, Z.; Chen, J.; Ling, H.C. Media Attention, Environmental Policy Uncertainty and Corporate Green Technology Innovation: Empirical Evidence from Chinese A-Share Listed Companies. *J. Ind. Eng. Eng. Manag.* **2023**, *37*, 1–15. [CrossRef]
28. Wang, H.; Sun, H.; Xiao, H.Y.; Xin, L. "Be Cautious" or "Win in Danger"? Environmental Policy Uncertainty and Green Innovation of Pollution-Intensive Enterprises. *Ind. Econ. Res.* **2021**, *2*, 30–41, 127. [CrossRef]
29. Sun, Y.H.; Zhang, C.X. Review and Reflection on China's Green Technology Innovation since the Reform and Opening-Up. *Soc. Sci. Guangdong* **2018**, *5*, 5–12.
30. Lu, Y. Green Policy and Employment in China: Is There a Double Dividend? *Econ. Res. J.* **2011**, *46*, 42–54.
31. Huang, R.; Liu, Y.; Yu, S. Does China's Carbon Emission Trading Policy Enhance ESG Performance in Construction Enterprises? Evidence from a Difference-in-Difference Estimation in China. *Systems* **2026**, *14*, 559. [CrossRef]
32. Dai, Y.; He, R. The Impact of Carbon Emissions Trading Policy on the ESG Performance of Heavy-Polluting Enterprises: The Mediating Role of Green Technological Innovation and Financing Constraints. *Sustainability* **2025**, *17*, 1365. [CrossRef]
33. Chen, Y.; Suk, S.; Liu, C. China's pilot emissions trading system as a stress test for substantive ESG improvement through green technological innovation. *Discov. Sustain.* **2026**, *7*, 829. [CrossRef]
34. Abu Seman, N.A.; Govindan, K.; Mardani, A.; Zakuan, N.; Mat Saman, M.Z.; Hooker, R.E.; Ozkul, S. The mediating effect of green innovation on the relationship between green supply chain management and environmental performance. *J. Clean. Prod.* **2019**, *229*, 115–127. [CrossRef]
35. Mao, G.; Li, M. The impact of ESG performance on corporate value is contingent on regional and firm innovation capacity. *Sustain. Dev.* **2026**, *6*, 8. [CrossRef]
36. Chen, J.; Shu, W.; Wang, X.; Sial, M.S.; Sehleanu, M.; Badulescu, D. The Impact of Environmental Uncertainty on Corporate Innovation: Empirical Evidence from an Emerging Economy. *Int. J. Environ. Res. Public Health* **2022**, *19*, 334. [CrossRef] [PubMed]