Industrial Engineering and Innovation Management (2025)
Clausius Scientific Press, Canada
DOI: 10.23977/ieim.2025.080111
ISSN 2522-6924 Vol. 8 Num. 1

The Impact of Carbon Emission Trading on Corporate Green Innovation: Evidence from High-Carbon Listed Companies in China

Anqi Wang

Central University of Finance and Economics, Beijing, China
wanganqi@email.cufe.edu.cn

Keywords: Carbon Emission Trading Market; Green Innovation; Environmental Regulation

Abstract: The carbon emission trading system is a crucial mechanism for China to participate in global climate governance and achieve its carbon peak and carbon neutrality goals. Using a sample of A-share high-carbon industry listed companies from 2011 to 2020, this study employs a difference-in-differences (DID) model to examine whether the establishment of pilot carbon emission trading markets effectively incentivizes corporate green innovation. The findings provide insights for the further implementation of a national carbon emission trading market in China. Empirical results reveal that: (1) The implementation of the carbon emission trading policy significantly increases corporate green innovation, promoting both high-quality and low-quality innovation; (2) The policy fosters green innovation by increasing firms' expected returns; (3) Further analysis indicates heterogeneous effects, with the impact being more pronounced in state-owned enterprises, firms receiving higher government subsidies, and those with greater media attention.

1. Introduction

Since the Industrial Revolution, greenhouse gas emissions have led to global warming, posing severe threats to the ecological environment and hindering sustainable economic and social development. As the world's largest carbon emitter, China has pledged to achieve carbon peaking by 2030 and carbon neutrality by 2060, aligning with international climate governance and national strategic goals. To achieve these targets, decoupling economic growth from fossil fuel consumption and energy demand is essential[1]. Carbon emissions reduction can be achieved either through capacity reduction or technological progress. However, while reducing production capacity directly lowers emissions, it may impede economic growth. In contrast, technological advancement enhances production efficiency and environmental sustainability, allowing for emissions reduction without sacrificing economic progress.

As a critical policy tool to achieve these goals, carbon emission trading system (ETS) have been widely implemented worldwide. Since the 12th Five-Year Plan for national economic and social development, China has gradually developed pilot carbon emission trading markets (ETMs). However, China's ETS was established relatively late, with the national ETS for the power generation sector only launching in 2021. This market still faces challenges such as immature pricing mechanisms, limited market participants, and low liquidity, potentially leading to inefficient carbon pricing and limited market vitality[2].

Enterprises play a vital role in both economic development and environmental governance. However, green innovation is characterized by strong externalities, high uncertainty, and significant risks, making firms less likely to invest in such innovations without adequate incentives[3]. Even when firms engage in green innovation, it may be driven by strategic responses rather than genuine efforts to achieve energy conservation and emissions reduction[2]. If policymakers focus solely on the quantity of innovation rather than quality, the policy may encourage low-quality, compliance-driven innovation rather than genuine technological breakthroughs. Therefore, in the context of global climate governance and China’s low-carbon transition, it is crucial to examine whether the carbon emission trading market effectively incentivizes corporate green innovation and how it influences firms’ decision-making processes.

This study makes several key contributions to the literature. Firstly, it shifts the focus from macroeconomic analyses to a micro-level perspective, examining how market-based environmental regulations influence corporate green innovation. By integrating the Porter Hypothesis with China’s ETS, this study enhances the theoretical understanding of policy-induced innovation. Secondly, this study innovatively identifies the mechanism through which carbon emission trading policy stimulate corporate green innovation, highlighting the role of firms' expected revenue in driving this process. Thirdly, it explores heterogeneous effects, revealing how factors such as ownership structure, government subsidies, and media attention moderate the impact of carbon trading policy on innovation. Lastly, it employs a quasi-natural experiment with a difference-in-differences (DID) approach, providing robust causal evidence while addressing endogeneity concerns. These contributions offer valuable insights for both academic research and policymaking in environmental economics and corporate innovation. By providing empirical evidence from China’s high-carbon industries, this study offers policy recommendations for enhancing the national ETS, fostering green innovation, and ultimately achieving China's dual carbon goals.

2. Institutional background and literature review

2.1 Institutional background

Carbon emissions trading is a policy tool to mitigate climate change through market mechanisms. In a carbon emissions trading system, regulatory authorities set a cap on greenhouse gas emissions for regulated entities and allocate or sell carbon allowances or permits to market participants. If a regulated entity emits less than its allocated allowances, it can sell the surplus allowances in the carbon market. Consequently, firms with lower abatement costs are incentivized to reduce emissions, while those with higher abatement costs can comply by purchasing allowances in the market. This trading mechanism enhances factor mobility, promotes efficient resource allocation, and drives green technological innovation for energy conservation and emissions reduction[4].

As the world's largest greenhouse gas emitter, China aimed to gradually establish a carbon emission trading market to regulate carbon emissions through market mechanisms. In 2011, the government announced the launch of carbon emission trading pilot programs in seven provinces and cities, including Beijing, Shanghai, Tianjin, Chongqing, Shenzhen, Guangdong, and Hubei.

Each pilot region developed its carbon emission trading mechanism based on local conditions, with carbon markets operating independently across different provinces and cities. The overall design follows three key principles: Firstly, the legal framework establishes the legitimacy and authority of the carbon ETS. Secondly, firms subject to emissions control are identified based on predetermined thresholds, and carbon allowances are allocated according to regional emissions reduction targets. Finally, during the compliance phase, firms’ actual emissions are verified, and they must surrender allowances equivalent to their emissions; non-compliant entities are subject to regulatory penalties.

Due to differences in economic development and energy structures, pilot regions vary in their total emissions cap, threshold criteria, and allocation methods. However, all pilots primarily target high-energy-consuming and high-emission industries. In terms of allowance distribution, most pilot programs allocate quotas through regulatory agencies, distribute allowances to firms at no cost, and permit the banking of surplus allowances for future use.

Since the implementation of the carbon emissions trading pilot policy, regional carbon markets have continued to expand, with both trading volume and carbon prices showing an upward trend. However, several challenges remain. Firstly, regional markets operate independently, leading to market fragmentation[5]. Secondly, the industry standard for inclusion in the carbon ETS requires further optimization. Thirdly, an oversupply of free allowances has resulted in excess supply, with inconsistent allocation standards across regions[2]. Finally, compared to mature international carbon markets, China's carbon ETM exhibits lower trading activity and relatively low carbon prices[5].

In July 2021, China took the power generation industry as a trial and officially launched the national carbon ETM. In the future, it is necessary to further improve the relevant policy standards of the national carbon ETM, gradually unify the quota allocation methods, and ensure that carbon trading can be circulated nationwide.

2.2 Literature Review

Since the Kyoto Protocol introduced the concept of carbon emission trading, a growing body of literature has examined the effects of carbon ETS mechanisms. Given that the European Union Emission Trading System (EU ETS) was established earliest and has the longest operational history, early studies primarily focused on the EU ETS[6].

With the launch of China’s carbon trading pilots, research has gradually expanded to the Chinese ETS. However, due to its late start and limited availability of firm-level green innovation data, early studies mostly relied on macro-level regional data. Findings at the regional level generally converge, indicating that carbon trading facilitates industrial upgrading. As an innovative market-based mechanism, carbon ETS has been shown to enhance energy and environmental efficiency in pilot regions and generate positive carbon reduction effects[7]. For instance, Mei Xiaohong (2015) examined the top ten provinces by carbon trading volume in China and found that ETS mechanisms help eliminate excess production capacity, with larger trading volumes driving regional industrial transformation and upgrading[8]. Furthermore, Du Li and Li Bo (2012) emphasized the financial attributes of carbon allowances, arguing that developing a robust carbon finance system can channel capital into clean industries, thereby promoting the development of low-carbon industries[9].

Regarding the impact of carbon ETS on corporate green innovation, some scholars argue that ETS stimulates firms’ green innovation activities. In terms of underlying mechanisms, Liu Ye and Zhang Xunchang (2017) employed a triple-difference (DDD) method and found that carbon trading policy increases R&D intensity among treated firms. The ETS enhances large firms’ cash flows, thereby directly boosting their innovation investments[10]. Similarly, Yang Qiulin et al. (2023) suggested that corporate R&D investment is negatively associated with current performance, and participation in carbon trading can mitigate the adverse impact of R&D investment on short-term corporate performance[11]. Further studies indicate that the positive impact of ETS on corporate green innovation intensifies as carbon prices rise[12] and carbon market liquidity improves[13]. Moreover, Song Deyong et al. (2021) found that using the benchmarking approach for initial carbon allowance allocation incentivizes firms below the benchmark to generate excess returns through green innovation, making it a more effective incentive mechanism than the historical allocation method[14].

However, some scholars hold opposing views, arguing that the carbon emissions trading system

(ETS) does not necessarily promote corporate green innovation. For example, Chen et al. (2021) found that after the implementation of carbon trading policy, firms opted to reduce production to meet emission reduction targets. Due to reduced cash flow and expected revenue, companies cut back on R&D investment, which hindered green innovation, leading to a 9.26% decrease in the proportion of green patents in the pilot regions after the policy implementation[15]. Similarly, Zhang et al. (2022) argued that lenient carbon allowances weakened the effectiveness of ETS. When carbon prices are low, high-polluting firms are more inclined to use R&D funds to purchase carbon allowances, leading to a crowding-out effect on R&D investment and diminishing the impact of carbon trading policy on innovation[4].

Based on existing research, early studies have mainly focused on the macro-level impacts of carbon emissions trading on regions such as provinces and cities, with relatively few studies examining its micro-level effects on enterprises. Current research on the micro-level effects and mechanisms of carbon ETS reveals several issues: (1) Empirical studies have mostly controlled only for city-level fixed effects without addressing individual-level differences, potentially leading to less accurate conclusions [2][13]; (2) Previous research has examined the impact of ETS on corporate R&D innovation but has not clearly identified its effect on green innovation or distinguished between high-quality and low-quality innovation[10]; (3) There is no consensus on the impact and mechanisms of ETS on corporate green innovation. Some scholars argue that the weak Porter hypothesis does not apply in China's current carbon trading market, where companies reduce production to meet emission reduction targets rather than engaging in green innovation[4] [15], while others suggest that the carbon emission trading market promotes green innovation.

3. Theoretical analysis and hypothesis formulation

The carbon emission trading system (ETS), as a market-based environmental regulation mechanism, effectively internalizes the external costs of environmental pollution through market pricing mechanisms. If a company's emissions exceed the free quota, it must purchase additional emission rights on the carbon trading market. This policy encourages companies to engage in green innovation activities by imposing cost constraints and offering potential benefits, reducing carbon emissions while maintaining output.

On one hand, the carbon emissions trading mechanism increases the cost of environmental pollution for companies. Under the pilot policy, various regions set emission limits for companies. The carbon ETS establishes emission rights as a scarce resource. Before the establishment of carbon markets, the cost associated with carbon emission from production activities was relatively low. According to economic theory, the environment is a public good with externalities, particularly negative externalities leading to pollution problems. In the early stages of China's environmental governance, command-and-control policies were the main regulatory approach, supplemented by pollutant discharge fee system. The government established pollution, technology, and environmental standards, and supervised compliance by enterprises. These command-and-control regulations placed a high environmental governance cost on the government. According to Coase theorem, the establishment of carbon emission markets clarified the property rights of emission rights. By pricing carbon emissions and privatizing this public good, the cost of carbon emissions borne by companies increases. The creation of carbon markets aims to minimize the total societal cost of pollution control, thus optimizing the allocation of environmental resources and achieving carbon emission reduction goals.

Under the carbon emission trading system, companies exceeding their allocated quotas are subject to government penalties. Enterprises in high-pollution industries, due to their inherent production methods, have higher energy consumption and larger carbon emissions, making them more susceptible to the effects of carbon emissions trading systems. If a company continues to use outdated technologies and production methods to meet government emission reduction targets, it will face the choice of reducing production or purchasing additional emission quotas. Both options increase costs and reduce profits, contrary to the company's goal of profit maximization. As the carbon market continues to develop and mature, the carbon pricing function will improve. According to supply-demand principles, the reduction in free carbon quotas makes emission rights scarcer, driving up their prices. High-carbon-emission companies will face a quota shortage, and the rising carbon price will lead to higher costs. When the cost of pollution increases, companies that fail to adjust in time will risk being eliminated from the market. Therefore, under this regulation, companies are motivated to proactively engage in green technological innovation, adjust production methods, and reduce environmental compliance costs.

Moreover, the establishment of the carbon market enhances the external regulatory pressure on companies. In recent years, extreme weather events, such as floods caused by global warming, have led to severe social losses, increasing public awareness of carbon reduction and environmental issues, and making the public more sensitive to excessive emissions. The government has set carbon neutrality and peak carbon goals, urging companies to cooperate in achieving national low-carbon development strategies, calculate their own carbon emissions, and disclose carbon information. Against the backdrop of economic green transformation, the market increasingly favors green investments, allocating resources to clean industries. According to stakeholder theory, companies should not only pursue shareholder wealth maximization but also consider social benefits. Therefore, in this context, companies need to respond to the environmental demands of external stakeholders, such as the government and the public, fulfill carbon reduction obligations, and build a positive corporate social image. The establishment of a legitimate carbon emissions trading market not only increases the explicit costs of high-carbon-emission companies by requiring them to purchase emission quotas but also increases the implicit pressure from external stakeholders to reduce emissions, effectively constraining their carbon emission behavior and addressing the externality of environmental pollution.

On the other hand, the carbon emissions trading mechanism can bring potential benefits for technological innovation. The scarcity of carbon quotas determines their market value. The Porter hypothesis suggests that appropriate environmental regulation can stimulate technological innovation in companies, thereby improving their competitiveness. The narrow version of the Porter hypothesis argues that flexible environmental regulations are more conducive to promoting technological innovation than mandatory ones. According to the Porter hypothesis, the carbon emissions trading mechanism, as a market-based environmental regulation, can more effectively encourage companies to increase innovation input, improve production efficiency, and enhance product competitiveness. Before the establishment of carbon emissions trading markets, companies engaged in green innovation, which had significant external spillover effects and did not receive corresponding compensation.

Under the carbon trading mechanism, if a company's actual emissions are lower than the allocated initial quota, the remaining carbon allowances can be sold in the carbon market for additional revenue. If companies expect to increase their revenue through carbon trading, they are more motivated to engage in green innovation, adopting lower-carbon, environmentally friendly production technologies to further reduce emissions and retain more quotas. By selling surplus quotas, companies can generate additional profits. The expectation of increased profits provides an incentive for green technological innovation. Additionally, companies with successful low-carbon development can apply for government subsidies and tax incentives. Therefore, the carbon emissions trading system encourages companies to innovate in green technologies, achieve carbon reduction, enhance product competitiveness, apply for subsidies and tax incentives, and trade saved carbon quotas for additional profits.

4. Research Design

4.1 Data sources

The subjects of the current carbon emissions trading system are primarily enterprises in high-pollution, high-emission industries, rather than all sectors. Since carbon-intensive industries are the main targets for emission control, companies in these sectors have stronger incentives to participate in carbon market. Given the availability of data, this study focuses on A-share listed companies in key carbon-emitting industries, examining their response to the establishment of the carbon emission trading market (ETS). The identification of key carbon-emitting industries follows the research of Liu Ye and Zhang Xunchang (2017)[10] and Li Chuang et al. (2023)[16], ensuring the validity and representativeness of the sample. Since the national carbon emission trading market officially opened in 2021, to avoid its impact, this study selects A-share listed companies in key carbon-emitting industries from 2011 to 2020 as the full sample. The green patent data for the empirical analysis is sourced from Chinese Research Data Services (CNRDS), while company characteristics and other relevant data are obtained from the CSMAR database. Before conducting the empirical analysis, the data is pre-processed with the following steps: (1) Excluding financial and insurance companies; (2) Excluding companies that were delisted or classified as ST or *ST in the given year; (3) Deleting companies with a significant number of missing values in key variables; (4) To mitigate the potential impact of outliers on regression results, continuous variables are winsorized at the 1st and 99th percentiles.

4.2 Variables and Measures

4.2.1 Explained variables

Enterprise green innovation (*Patent*). Corporate innovation is commonly assessed through R&D investment and patent output, with the latter providing a more direct measure of innovation capability. Green patents refer to invention, utility model and design patents centered on green technologies. Since the technological innovation requirements of appearance patents are relatively low, this study chooses the sum of the number of green invention patents and green utility model patents applied for as the core indicator for assessing the green innovation capability of enterprises.

4.2.2 Explanatory variables

Carbon Emissions Trading Pilot Policy (Treat*Post). Treat is a grouping variable indicating whether a region is included in the carbon emission trading pilot. Firms in high-carbon-emission industries located in pilot regions form the treatment group (Treat = 1), while those in non-pilot regions constitute the control group (Treat = 0). Post is a dummy variable representing the policy intervention. It takes a value of 1 for years during and after the establishment of the carbon trading pilot and 0 for years prior to policy implementation.

4.2.3 Control variables

In addition to the impact of the carbon ETS on corporate green innovation, other factors also influence firms' decisions to pursue green innovation. To mitigate estimation bias, this study incorporates control variables based on prior research[10]. Detailed definitions and descriptions of variables are shown in Table 1.

Table 1 Definitions of variables

Type of Variable	Variables	Definitions
Explained Variables	*Patent*	The total number of green invention patents and green utility model patents applied
	I_Patent	The number of green innovation patent applications
	U_Patnet	The number of green utility model patent applications
Explanatory Variables	*Treat*	A binary variable indicating whether a firm is located in a pilot region (1 = yes, 0 = no)
	Post	A binary variable indicating whether the carbon emission trading policy was implemented in the current year or later (1 = yes, 0 = no)
Control Variables	*Size*	Ln(total assets at the end of the year)
	Lev	Total liabilities/total assets
	BM	Net assets/company market value
	ROE	Net profit/total assets
	Growth	Current operating income change / previous operating income
	Share	Number of shares held by enterprise management

4.3 Model design

The Difference-in-Differences (DID) method is commonly used to evaluate policy effects. Its principle involves comparing the differences before and after policy implementation between the treatment and control groups to estimate the net effect of the policy on the treatment group. These differences change significantly before and after the policy, reflecting both the inter-group differences at a given time and the intra-group differences over time. The carbon emission trading policy exhibits exogenous characteristics, making it suitable for the application of the DID method. Therefore, this study constructs the baseline DID model shown in equation (1) to examine the actual impact of the carbon emission trading policy on corporate green innovation.

To test the impact of accelerated depreciation policy for fixed assets on enterprises' green technology innovation, we set up model (1) for causal identification test:

$$Patent_{i,t} = \beta_0 + \beta_1 Treat_i * Post_{i,t} + \beta_2 Control_{i,t} + \beta_3 \sum Year_t + \beta_4 \sum Company_i + \varepsilon_{i,t} \quad (1)$$

In equation (1), $Patent_{i,t}$ is the dependent variable representing the level of green innovation for *firm(i)* in *year(t)*. $Treat_i$ is the reginal grouping variable, and $Post_{i,t}$ represents the policy implementation period. $Treat_i * Post_{i,t}$ is the policy dummy variable, indicating whether firm I in year t is subject to carbon emission trading. β_1 reflects the impact of the carbon emission trading policy on corporate green innovation. $Control_{i,t}$ represents control variables, capturing other factors influencing green innovation that vary across *firm(i)* or *year(t)* is the unobservable random disturbance term.

To enhance the model's accuracy, both individual and time fixed effects are controlled. $\sum Company_i$ represents firm-specific effects, controlling factors that influence green innovation but do not vary over time. $\sum Year_t$ represents time fixed effects, controlling for unobservable factors that vary over time.

5. Empirical Results and Analyses

5.1 Descriptive Statistics

The descriptive statistics of the main variables are presented in Table 2. The results indicate that among all main variables, the number of green patents (*Patent*) exhibits the highest standard deviation

(37.88).

Table 2 Descriptive statistics (I)

Variables	N	Mean	SD	Min	Max
Patent	11,432	5.188	37.88	0	1,565
I_Patent	11,432	3.106	31.85	0	1,381
U_Patent	11,432	2.082	9.027	0	288
Treat	11,432	0.262	0.440	0	1
Post	11,432	0.693	0.461	0	1
Treat*Post	11,432	0.185	0.388	0	1
Size	11,432	22.20	1.346	19.61	26.15
Share	11,432	36.72	16.06	9.110	75.90
ROE	11,432	0.0545	0.167	-1.022	0.370
Growth	11,432	0.0715	0.286	-1.288	0.789
BM	11,432	0.360	0.180	0.00299	0.799
Lev	11,432	2.761	3.444	0.695	11.50

Table 3 compares the treatment group (*Treat*=1) and the control group (*Treat*=0). The average number of green patents in the treatment group is 11.4, while that in the control group is 2.989.

Table 3 Descriptive statistics (II)

	Treatment group: Treat=1, N=2991				Control group: Treat=0, N=8441			
Variables	Mean	SD	Min	Max	Mean	SD	Min	Max
Patent	11.40	71.72	0	1,565	2.989	10.15	0	252
I_Patent	7.538	61.10	0	1,381	1.535	6.470	0	191
U_Patent	3.858	15.06	0	288	1.454	5.341	0	168
Treat	1	0	1	1	0	0	0	0
Post	0.707	0.455	0	1	0.688	0.464	0	1
Treat*Post	0.707	0.455	0	1	0	0	0	0
Size	22.38	1.526	19.61	26.15	22.13	1.270	19.61	26.15
Share	37.44	16.47	9.110	75.90	36.47	15.91	9.110	75.90
ROE	0.0597	0.141	-1.022	0.370	0.0527	0.175	-1.022	0.370
Growth	0.0742	0.279	-1.288	0.789	0.0706	0.289	-1.288	0.789
BM	0.362	0.176	0.00299	0.799	0.359	0.182	0.00299	0.799
Lev	2.515	3.206	0.695	11.50	2.849	3.521	0.695	11.50

5.2 Baseline Results

Table 4 analyzes the impact of the carbon emission trading policy on corporate green innovation. Column (1) presents the univariate regression results of the policy's effect on the total number of green patents. Column (2) includes firm size, profitability, and ownership structure as control variables. Column (3) further incorporates time and firm fixed effects. Across all three specifications, the coefficient of Treat*Post remains significantly positive at the 1% level, supporting Hypothesis H1. From an economic perspective, the results in Column (3) indicate that, on average, the number of green patents in high-carbon firms within pilot regions increases by 5.547 following the policy implementation. This corresponds to 48.66% of the mean green patent count in the treatment group (11.40) and 106.92% of the full-sample mean (5.188). These findings confirm that carbon emissions trading significantly promotes corporate green innovation, thereby validating Hypothesis H1.

Table 4 Baseline regression results

	(1)	(2)	(3)
VARIABLES	Patent	Patent	Patent
Treat*Post	9.783***	7.540***	5.547***
	(1.677)	(1.475)	(1.766)
Size		6.024***	1.442**
		(0.646)	(0.581)
Lev		-0.187***	-0.045
		(0.052)	(0.041)
BM		3.116*	0.981
		(1.631)	(1.411)
ROE		-1.775*	0.424
		(0.952)	(0.636)
Growth		-3.232***	-0.329
		(1.082)	(0.540)
Share		0.118***	0.071***
		(0.029)	(0.027)
Constant	3.378***	-130.858***	-30.654**
	(0.211)	(14.530)	(12.850)
N	11,432	11,432	11,309
R-squared	0.010	0.063	0.777
Controls	NO	YES	YES
Company FE	NO	NO	YES
Year FE	NO	NO	YES

Note: *, **, *** indicate that the statistics are significant at the 10%, 5%, and 1% levels respectively, and robust standard errors are in parentheses, so as follows.

6. Robustness Test

6.1 Parallel trend test

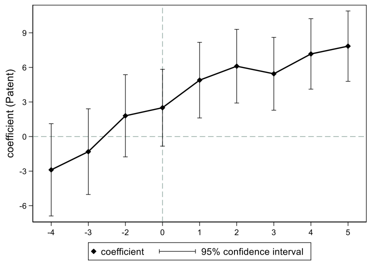

Figure 1 Parallel trend test

The validity of the difference-in-differences (DID) method relies on the parallel trend assumption, which requires that the outcome variables of the treatment and control groups follow a common trend before policy implementation. To verify this assumption, this study introduces a pre-post policy impact term. Figure 1 presents the regression coefficients of the impact of the carbon emissions trading policy on corporate green innovation within a 95% confidence interval. The results indicate that the pre-policy impact terms are not statistically significant, suggesting no significant difference in green innovation levels between high-carbon publicly listed firms in the treatment and control groups before policy implementation. Furthermore, during the first five years following policy implementation, the regression coefficients remain positive and statistically significant at the 1% level. This confirms that the carbon emission trading policy has a significant and stable impact on green innovation over time, consistent with the theoretical expectations of this study.

6.2 Placebo test

To verify that the observed increase in corporate green innovation is indeed driven by the carbon emission trading policy rather than unobserved factors, this study conducts a placebo test following Zhou et al. (2018)[17]. Specifically, the interaction term Treat*Post is randomly reassigned 500 times, and regression analyses are performed to examine whether the estimated coefficients and p-values significantly differ from the baseline results. Figure 2 presents the placebo test results, where the primary axis represents the regression coefficients and the secondary axis denotes the p-values. The simulated coefficients are centered around 0 and approximately follow a normal distribution. The vertical dashed line marks the actual estimated coefficient (5.547) from the baseline regression, which lies outside the distribution range of the simulated coefficients. Additionally, the horizontal dashed line represents the baseline p-value (0.002), with most simulated p-values exceeding this threshold, indicating statistical insignificance.

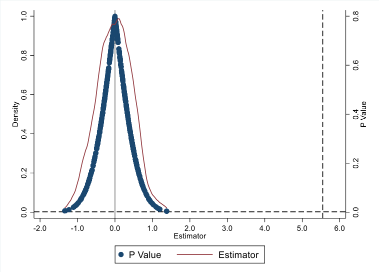

Figure 2 Placebo test

These findings confirm that randomly assigned placebo treatments do not yield an effect similar to the observed policy impact. Thus, the assumption $\gamma = 0$ holds, suggesting that unobserved factors do not bias the estimated coefficient. This reinforces the robustness of the baseline results, demonstrating that the carbon emission trading policy significantly promotes corporate green innovation.

6.3 Propensity score matching(PSM)

The difference-in-differences (DID) model assumes that the treatment and control groups are randomly assigned. However, the selection of pilot regions for the carbon emission trading policy was not random but influenced by multiple factors that may also affect corporate innovation. This non-random selection could lead to selection bias if the control group is assumed to represent the counterfactual outcome of the treatment group.

To address this concern, we employ the propensity score matching with difference-in-differences (PSM-DID) method to mitigate potential endogeneity issues. The key steps are as follows: (1) We estimate propensity scores using a Probit model with control variables from baseline model (1) to predict the likelihood of a firm being in the treatment group. (2) Using the nearest-neighbor matching method with a 1:2 ratio, we select control firms with the closest propensity scores to ensure comparability. The post-matching balance test confirms that the matched samples are statistically similar. (4) Finally, we re-estimate model (1) using the matched sample. As shown in Table 5, the coefficient of Treat*Post remains positive and statistically significant at the 1% level, confirming the robustness of our findings that the carbon emissions trading policy significantly promotes green innovation in high-carbon industries.

Table 5 The regression results of PSM-DID

	(1)	(2)
VARIABLES	Patent	Patent
*Treat*Post*	5.172***	5.327***
	(1.809)	(1.843)
Constant	5.391***	-27.704
	(0.462)	(18.890)
Observations	8,810	8,810
R-squared	0.783	0.783
Controls	NO	YES
Company FE	YES	YES
Year FE	YES	YES

6.4 Substitution of explanatory variables

Green innovation involves high uncertainty, and its commercialization is difficult to predict. High-carbon firms, often reliant on traditional technologies, may lack intrinsic motivation for green innovation and respond to external regulatory pressure strategically rather than substantively. This could mean pursuing innovation mainly to secure government subsidies or external investments rather than genuinely improving green capabilities[2]. Therefore, evaluating policy effectiveness requires a careful analysis of firms' underlying motivations and true intentions.

According to Zhang et al. (2023), green invention patents represent substantive green technological innovation (high-quality innovation), while green utility model patents serve as a proxy for strategic green innovation (low-quality innovation) [18]. Building on this framework, this study differentiates between two types of green innovation by replacing the dependent variable in the baseline regression. As shown in Table 6, the carbon emission trading policy has a significant positive impact on both types of innovation, with coefficients of 3.321 and statistically significant at the 5% level and 2.226 (1% level), respectively. These findings confirm the robustness of our results, indicating that the policy drives both substantive and strategic green innovation.

Table 6 Substitution of explanatory variables

	(1)	(2)
VARIABLES	I_Patent	U_Patent
Treat*Post	3.321**	2.226***
	(1.490)	(0.422)
Constant	-12.204	-18.450***
	(10.553)	(3.752)
Observations	11,309	11,309
R-squared	0.784	0.601
Controls	YES	YES
Company FE	YES	YES
Year FE	YES	YES

7. Expansion Analysis

7.1 Analysis of the Expected Profit Mechanism

Following Liu and Zhang (2017)[10], this study employs return on assets (ROA) as a mechanism variable to assess the expected profit effect of carbon emission trading. Firms with surplus carbon allowances can generate additional revenue by selling them in the carbon market, leading to increased cash inflows, higher profitability, and improved ROA. Consequently, the ability to profit from surplus allowances incentivizes firms to pursue green innovation, reduce carbon emissions, and optimize allowance utilization for sustained long-term gains.

If the implementation of the carbon emission trading system leads to higher corporate profitability, as indicated by an increase in ROA, it would confirm the existence of the expected profit effect. As is shown in Table 7, Columns (1) to (5) report regression results with ROA lagged by four periods. The coefficient of the interaction term (Treat*Post) remains significantly positive at least at the 5% level, indicating a robust and persistent expected profit effect. These findings support the conclusion that the emissions trading policy strengthens firms' incentives for green innovation by increasing their expected returns.

Table 7 Regression analysis of the Expected Profit Mechanism

	(1)	(2)
VARIABLES	SA	SA
*Treat*Post*	-0.009***	-0.015***
	(0.001)	(0.001)
Constant	-3.034***	-3.171***
	(0.017)	(0.020)
Controls	YES	YES
Company FE	NO	YES
Year FE	NO	YES
N	20,676	20,572
R-squared	0.853	0.982

7.2 Heterogeneity Analysis

7.2.1 Nature of Enterprises

China's socialist public ownership system requires state-owned enterprises (SOEs) to fulfill both economic and social responsibilities. As key implementers of national policies, SOEs play a crucial role in promoting green economic development. They are subject to greater government intervention and are often assigned environmental targets. Consequently, SOEs bear a heavier burden in environmental governance. Additionally, their economies of scale and monopoly advantages provide them with greater R&D capital and talent, ensuring sustained innovation efforts. The combination of carbon emissions trading policy effects and government support in terms of resources and funding further incentivizes SOEs to engage in green innovation.

In contrast, non-SOEs are more profit-driven, prioritizing profit maximization. Market-based environmental regulations may impact private enterprises, but their resource constraints often limit their ability to bear the costs and risks associated with green innovation. Given limited innovation budgets, non-SOEs tend to allocate resources to core product development rather than green innovation, reducing the policy's effectiveness in driving green transformation. Therefore, we hypothesize that the carbon emissions trading policy has a more significant positive impact on green innovation in SOEs than in non-SOEs.

To test this, we introduce the dummy variable State, which equals 1 for SOEs and 0 otherwise. Regression results in Table 8 show that the coefficient for SOEs is 13.033, significantly positive at the 1% level. The Fisher's Permutation test confirms a statistically significant difference between the two groups, validating the moderating role of ownership property. This indicates that the carbon emission trading policy has a stronger effect in promoting green innovation among state-owned enterprises.

Table 8 Results of the regression based on ownership groups

	(1)	(2)
VARIABLES	*state-owned*	*non-state-owned*
*Treat*Post*	13.033***	-1.481**
	(2.204)	(0.711)
Constant	-61.573**	-71.500***
	(29.443)	(7.883)
N	4,312	4,895
R-squared	0.797	0.564
Controls	YES	YES
Company FE	YES	YES
Year FE	YES	YES
Fisher's Permutation Test	-14.514*** (p=0.000)	

7.2.2 Government Subsidies

With the implementation of environmental regulations, firms adjust their production methods and invest in green innovation. However, this process requires substantial financial and human capital. Due to the confidentiality of innovation and the negative externalities of green innovation, firms often face financial constraints. Government subsidies help mitigate these constraints through several mechanisms. Firstly, they directly alleviate short-term financial shortages, ensuring continued investment in green innovation. Secondly, subsidies send positive signals to external investors, enhancing firms' financing capabilities. Thirdly, they partially offset the negative externalities associated with green innovation, incentivizing firms to adopt greener technologies. Therefore, government subsidies are expected to positively moderate the relationship between carbon emissions trading policies and corporate green innovation.

To test this hypothesis, following Mei and Cui (2023)[19], we conduct an empirical analysis using logged government subsidy data disclosed by listed firms. The dummy variable Subsidy is used to indicate subsidy levels, where Subsidy = 1 if a firm receives subsidies above the sample median and Subsidy = 0 otherwise.

Table 9 Results of the regression based on government subsidies

	(1)	(2)
VARIABLES	high subsidies	low subsidies
*Treat*Post*	5.520**	0.262
	(2.438)	(0.577)
Constant	-96.403***	-23.259***
	(34.634)	(5.422)
N	4,845	4,847
R-squared	0.838	0.343
Controls	YES	YES
Company FE	YES	YES
Year FE	YES	YES
Fisher's Permutation Test	-5.258** (p=0.020)	

Regression results in Table 9 show that the coefficient for firms receiving higher subsidies is 5.520 and is statistically significant at the 5% level, while the coefficient for firms receiving lower subsidies is not significant. Fisher's permutation test confirms a significant difference between the two groups, supporting the hypothesis that government subsidies positively moderate the effect of carbon emissions trading policies on green innovation. Higher government subsidies strengthen firms' incentives to engage in green innovation following the implementation of the carbon emissions trading policy.

7.2.3 Media attention

According to stakeholder theory, media serve as external stakeholders that reflect public concerns and influence corporate behavior. Media attention exerts external pressure on firms, compelling them to balance profit maximization with the interests of various stakeholders. Negative media reports on corporate pollution and excessive emissions can attract public scrutiny and reinforce expectations for corporate environmental responsibility. Prior research, such as Yang et al. (2023)[20], has also confirmed this effect. Thus, this study hypothesizes that firms with higher media attention will experience a stronger positive impact of the carbon emissions trading policy on green innovation.

Following Mei and Cui (2023)[19] and Yang et al. (2023)[20], we measure media attention (*media*) using the number of negative financial news reports in print newspapers. Given concerns about the credibility and quality of online media coverage, only print financial reports are considered. The formula for media attention is media = ln(1 + annual number of negative news reports), with data sourced from the CNRDS database. Firms are classified into high and low media attention groups based on the median value of media attention.

Regression results in Table 10 show that in the high media attention group, the estimated coefficient of Treat*Post is 4.651, significant at the 1% level, whereas the coefficient in the low media attention group is not significant. A Fisher combination test confirms a significant difference between the two groups. These findings suggest that firms facing greater media scrutiny are subject to stronger stakeholder oversight, enhancing the effectiveness of the carbon emissions trading policy in promoting green innovation.

Table 10 Results of the regression based on media attention

	(1)	(2)
VARIABLES	high media attention	low media attention
*Treat*Post*	4.651***	-0.181
	(1.729)	(0.854)
Constant	-46.912*	-69.898***
	(25.159)	(10.716)
N	4,264	4,039
R-squared	0.913	0.636
Controls	YES	YES
Company FE	YES	YES
Year FE	YES	YES
Fisher's Permutation Test	-4.832** (p=0.040)	

8. Conclusions and Policy implications

The carbon emissions trading market is an important tool for China’s participation in global climate governance, aimed at achieving carbon peaking and carbon neutrality. Its primary goal is to balance economic growth with environmental sustainability by reducing carbon emissions and fostering green development. However, since green innovation involves both environmental and innovation-related externalities, enterprises may lack sufficient motivation to engage in it. Therefore, it is crucial to evaluate the effectiveness of this market mechanism in practice and assess whether it can successfully encourage enterprises to engage in green innovation and achieve the intended goal of carbon reduction.

This study examines A-share listed companies in high-carbon industries from 2011 to 2020, utilizing China’s carbon emissions trading pilot policy as a quasi-natural experiment. Using Difference-in-Differences (DID) method and panel fixed effects models, we investigate the relationship between carbon emission trading and corporate green innovation, supported by Coase's Theorem, Porter Hypothesis, and Stakeholder Theory. The findings are as follows:

Firstly, the establishment of carbon emission trading system promotes corporate green innovation. The implementation of the carbon emission trading policy significantly increases the number of green patent applications by enterprises. It not only fosters low-quality green innovation, as indicated by green utility model patents, but also promotes high-quality green innovation, as reflected in green invention patents. This suggests that the carbon trading system, as a market-driven environmental regulation, effectively incentivizes enterprises to purse green innovation. Considering China's national context, it provides empirical support for the weak Porter hypothesis. The conclusion holds robust across various tests (parallel trends test, placebo tests, PSM-DID analysis, replacement of the explanatory variable), confirming the policy’s significant and stable effect.

Secondly, the carbon emission trading system incentivizes enterprises to engage in green innovation by increasing their expected returns. According to Coase’s Theorem, the carbon trading system internalizes the cost of carbon emission, requiring firms to bear the pollution cost while establishing carbon allowances as a valuable and scarce resource. When firms anticipate that reducing emissions can help them save carbon allowances, which can then be sold in the carbon market for excess returns, they are motivated to pursue green innovation to achieve emission reductions. Empirical results confirm that the carbon trading system significantly enhances firms' return on assets. This positive effect remains robust even after lagged treatment, indicating that the impact on green innovation is long-term and persistent rather than merely short-term.

Thirdly, the impact of the carbon emission trading system on corporate green innovation exhibits heterogeneity, influenced by ownership structure, government subsidies, and media attention. The policy has a stronger effect on state-owned enterprises, firms with higher government subsidies, and those with greater media attention. State-owned companies, due to stronger government intervention and social responsibility, play a more significant role in environmental governance. Their larger scale and better resource access also reduce constraints on innovation. Government subsidies help alleviate financial pressure in the inherently uncertain R&D process, sustaining firms’ green innovation efforts. In addition, media scrutiny increases firms' motivation to innovate.

Based on the above research conclusions, this study proposes the following suggestions. Firstly, China should enhance and improve the carbon emission trading system. The government should continue to promote and refine the carbon ETS. Initially, the allocation of carbon allowances was free, resulting in low carbon prices. The government should gradually reduce free allowances to increase scarcity. Additionally, the threshold for carbon emission trading is currently high, covering only certain industries like power. This should be expanded to include more sectors. Furthermore, regional carbon markets need to be integrated to improve market liquidity, enabling the carbon market to better perform its carbon pricing function. This will incentivize enterprises to pursue continuous green innovation, reduce carbon emissions, and generate profits through carbon trading.

Secondly, when implementing the carbon emission trading system, the government should provide appropriate subsidies to enterprises, leveraging the leading role of state-owned enterprises while considering the response of non-state-owned enterprises. It is essential to continue encouraging state-owned enterprises to contribute to carbon reduction while further incentivizing non-state-owned enterprises to engage in green innovation. Due to constraints such as smaller scale and financial limitations, non-state-owned enterprises may be less responsive to the policy. Therefore, the government should offer targeted subsidies to support green innovation and enhance the policy's guiding effect.

Thirdly, firms should actively engage in the carbon emission trading market to enhance their green innovation capabilities and improve their social image and value. Companies should align their development goals with national low-carbon strategies and invest more in green innovation to achieve emission reductions. Participating in the carbon market not only allows firms to generate profits by selling carbon allowances but also helps enhance competitiveness and corporate social responsibility, ultimately improving both environmental and economic outcomes.

References

[1] Lin Boqiang. China's High-quality Economic Growth in the Process of Carbon Neutrality[J]. Economic Research Journal, 2022, 57(01): 56-71.

[2] Shen Hongtao, Huang Nan. Will the Carbon Emission Trading Scheme Improve Firm Value?[J]. Finance & Trade Economics, 2019, 40(01): 144-161.

[3] Huang Zhibin, Zhang Tao. Analysis on Enterprises' Green Technology Innovation and Its Obstruction Factors[J]. Studies in Dialectics of Nature, 2018, 34(08): 129-133.

[4] Zhang W, Li G, Guo F. Does carbon emissions trading promote green technology innovation in China?[J]. Applied Energy, 2022, 315: 119012.

[5] Shen Chen, Lin Peina. Study on the Characteristics and Market Risks of the Carbon Emissions Trading Pilot Market in China[J]. Industrial Economic Review, 2017, 8(04): 123-134.

[6] Chen Xiaohong, Wang Zhiyun. Empirical Research on Price Impact Factor of Carbon Emission Exchange: Evidence from EU ETS[J]. Systems Engineering, 2012, 30(02): 53-60.

[7] Liu Haiying, Guo Wenqi. Carbon Emission Trading Policy Pilot and Energy-Environmental Efficiency: An Empirical Study of 287 Prefecture-Level Cities in China[J]. Journal of Xi'an Jiaotong University (Social Sciences), 2022, 42(05): 72-86.

[8] Mei Xiaohong. On the Influence of China's Carbon Finance Market on Regional Economic Structure—Based on the Panel Data Econometric Model[J]. Journal of Technical Economics & Management, 2015(01): 108-111.

[9] Du Li, Li Bo. Adjustment and Upgrading of Industrial Structure by Utilizing Carbon Financial System[J]. Economist, 2012(06): 45-52.

[10] Liu Ye, Zhang Xunchang. Carbon Emission Trading System and Enterprise R&D Innovation: An Empirical Study Based on Triple Difference Model[J]. Economic Science, 2017(03): 102-114.

[11] Yang Qiulin, Liu Jie, Tang Yang. R&D Investment, Carbon Emission Trading, and Enterprise Performance—Empirical Evidence from A-share Listed Companies in Carbon Trading Pilot Provinces and Cities[J]. Communication of Finance and Accounting, 2023(01): 60-65.

[12] Wei Lili, Ren Liyuan. Can Carbon Emissions Trading Promote Enterprise Green Technological Innovation—Based on the Perspective of Carbon Price[J]. Lanzhou Academic Journal, 2021(07): 91-110.

[13] Hu Jun, Huang Nan, Shen Hongtao. Can Market-Incentive Environmental Regulation Promote Corporate Innovation?—A Natural Experiment Based on China's Carbon Emissions Trading Mechanism[J]. Journal of Financial Research, 2020(01): 171-189.

[14] Song Deyong, Zhu Wenbo, Wang Banban. Micro-empirical Evidence Based on China's Carbon Trading Companies: Carbon Emissions Trading, Quota Allocation Methods and Corporate Green Innovation[J]. China Population, Resources and Environment, 2021, 31(01): 37-47.

[15] Chen Z, Zhang X, Chen F. Do carbon emission trading schemes stimulate green innovation in enterprises? Evidence from China[J]. Technological Forecasting and Social Change, 2021, 168: 120744.

[16] Li Chuang, Wang Zhijia, Wang Liping. The Impact of Carbon Emission Trading Policy on Firms' Green Technology Innovation: Based on Instrumental Variables and Triple Difference Test[J]. Science of Science and Management of S.& T., 2023, 44(05): 15-33.

[17] Zhou Mao, Lu Yi, Du Yan, et al. Special Economic Zones and Region Manufacturing Upgrading[J]. China Industrial Economics, 2018(03): 62-79.

[18] Zhang M, Yan T, Gao W, et al. How does environmental regulation affect real green technology innovation and strategic green technology innovation?[J]. Science of The Total Environment, 2023, 872: 162221.

[19] Mei Linhai, Cui Wanling. Research on the Impact Mechanism of Carbon Emission Trading System on Enterprise Green Innovation[J]. Industrial Economic Review, 2023, 14(04): 38-58.

[20] Yang Zhen, Chen Jin, Ling Hongcheng. Media Attention, Environmental Policy Uncertainty and Firm's Green Technology Innovation: Empirical Evidence from Chinese A-Share Listed Firms[J]. Journal of Industrial Engineering and Engineering Management, 2023, 37(04): 1-15.