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Does Carbon Emission Trading Affect China's Green Innovation? An Exploration from the Perspective of the Enterprise Lifecycle

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Abstract: At different lifecycle stages, enterprises possess differentiated resource endowments and innovation needs, leading to variations in the effect of carbon emission trading policies on their green innovation. This study analyzes the impact of China's carbon emission trading policy on green innovation, using A-share listed firms in Shanghai and Shenzhen between 2010 and 2022 as samples, from the perspective of the enterprise lifecycle. The results validate the Porter hypothesis, showing that the policy stimulates green innovation, especially in the growth and maturity stages of enterprises. However, the extent of this impact varies across enterprise scale heterogeneity, heterogeneity in the proportion of independent directors, heterogeneity in the level of green innovation and regional heterogeneity. The carbon emission trading policies can mitigate financing constraints and improve capital investment to foster green innovation, especially for mature enterprises. The findings not only enhance the theoretical investigation of flexible market-oriented environmental regulatory mechanisms but also provide valuable insights for advancing the growth of China's low-carbon economy.

Keywords: carbon emission trading policy; green innovation; enterprise lifecycle; heterogeneity effect; mediation effect

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1. Introduction

As one of the largest developing countries in the world, China is also the country with the highest carbon emissions. The rapid economic growth of China has led to a significant ecological burden, which necessitates abandoning the outdated notion of "development before governance" and instead promoting "green" and "innovation" [1–5]. Enterprises, as the focal point of economic change and development, have a duty to promote green, low-carbon, and sustainable practices. However, as innovative organizations, enterprises often lack adequate incentive to participate in environmentally friendly innovation, due to the characteristics of environmental public goods [6–9]. In order to solve this issue, China has implemented carbon emission trading pilot programs progressively since 2011. Unlike the Emission Trading Scheme in other countries, China's pilot ETSs implemented diversified policy designs instead of using a uniform framework [10,11]. Current research is to investigate the causal impact of the pilot ETS project on enterprise green innovation in China from the perspective of enterprise lifecycle. This study is highly significant in assisting relevant departments to implement precise carbon trading regulations, help enterprises in enhancing green innovation capabilities, and achieve environmentally friendly and sustainable growth.

The Porter hypothesis asserts that rigorously yet thoughtfully crafted environmental regulations have the potential to stimulate green innovation [12,13]. Carbon emissions trading incentivizes enterprises to reduce carbon emissions by increasing abatement costs

[14,15], thereby driving green technological innovation within these enterprises [16–19]. However, the "compliance cost hypothesis" suggests that environmental regulations increase the cost burden on enterprises, thereby crowding out production and innovation investments to a certain extent [20]. Some scholars argue that its effects may vary depending on factors such as industry and region [19,21–23]. According to the enterprise lifecycle theory, an enterprise exhibits lifecycle characteristics similar to a biological organism from its inception to its demise. At different lifecycle stages, the enterprise's resource endowments, organizational characteristics, production and operation modes, and other factors vary [24–26]. When applying the enterprise lifecycle perspective to the impact of carbon trading policy on green innovation, it can be found that the enterprise's green innovation behaviors will exhibit distinct characteristics at different stages. Specifically, for enterprises in the growth phase, the carbon emission trading system may stimulate their willingness to reduce carbon emissions and improve resource utilization efficiency through innovation. On the other hand, for enterprises in the maturity phase, the carbon emission trading system may prompt them to innovate in order to adapt to new market rules and environmental requirements [27–30]. However, we still know little about the effects from the perspective of the enterprise lifecycle. This paper examines how carbon emission trading regulations affect companies' efforts to innovate sustainably, from the perspective of enterprise lifecycle.

Compared to the existing literature, the marginal contribution of this paper is mainly reflected in the following points. First, this paper incorporates the lifecycle theory into the discussion of the impact of carbon emissions trading policies on corporate green innovation. It provides a nuanced analysis of the effects of carbon emission trading policies on enterprises across different lifecycle stages. We find that the carbon emission trading policies have a significant positive impact on green innovation in the growth stage and maturity stage, while the effect of declining enterprises is not significant. This result is still valid after robustness tests. Second, the enterprise scale heterogeneity, the proportion of independent director heterogeneity, the level of green innovation heterogeneity and regional heterogeneity are considered from the perspective of the enterprise lifecycle. The paper considers the role of enterprise size and corporate governance structures, particularly the proportion of independent directors, in shaping the response to carbon emission trading policies. This analysis adds a new dimension to the understanding of how internal governance factors influence enterprises' environmental strategies. Meanwhile, the paper highlights the importance of encouraging continuous green innovation in enterprises with a high level of green innovation, while also warning against the risks of over-innovation and waste. It underscores the importance of regional heterogeneity in shaping the outcomes of carbon emissions trading policies. Third, the paper takes an integrated perspective by examining both financing constraints and capital investment mechanisms in the context of carbon emission trading policies from the perspective of the enterprise lifecycle.

The remainder of the paper is organized as follows. Section 2 provides the related literature and theoretical hypotheses. Section 3 describes the research methods and data sources. Section 4 explains the empirical results. Section 5 presents the conclusion and policy implications.

2. Literature Review and Hypotheses Development

2.1. Literature Review on the Effects of Carbon Trading Policy on Green Innovation

The carbon emission trading policy is a market-based environmental regulation tool. According to the Porter hypothesis, well-designed environmental regulations can motivate enterprises to invest in technological innovation, thereby strengthening their competitive position in the market [12,31,32]. On the one hand, environmental regulations can offer subsidies to enterprises for their green innovation efforts through financial incentives [33]. On the other hand, enterprises possessing stronger green innovation capabilities can garner more economic benefits through patent transfers, emissions trading, and other means [34]. Some scholars analyze this issue from the perspective of the "compliance cost" theory, pointing out that environmental regulations increase production costs and inhibit the green innovation of enterprises [20,35,36].

The green innovation effect of carbon emission trading, as a typical market-incentive environmental regulation policy, has also received widespread attention [17,37–39]. The existing literature primarily focuses on the overall design and other market performances of China's carbon emissions trading system, with less attention paid to green technological innovation [40–43]. The existing empirical research has shown that China's carbon emission trading policy plays a beneficial role in encouraging green innovation. Some scholars have confirmed its positive effect, highlighting the policy's effectiveness as a market-based environmental regulation tool [39,44,45]. The impact of this policy's execution is also influenced by the degree of liquidity of the carbon emission trading market and the capacity of companies to reduce costs [46]. The carbon emission trading policy effectively promotes green innovation activities among industrial enterprises [45], manufacturing enterprises [47,48], energy enterprises [44] and electric power enterprises [49] in the pilot areas. Considering the heterogeneity of the impact of carbon trading policies on enterprises' green innovation, this positive impact is particularly evident in large-scale enterprises, state-owned enterprises, and enterprises with high levels of compliance with regulations in the eastern region of China [27,50,51].

Furthermore, scholars have investigated the mechanism by which carbon emission trading regulations promote green innovation in enterprises. The carbon emission trading price plays an essential role in the carbon emission trading mechanism [52,53]. The market's supply and demand for carbon emission permits are reflected in the fluctuating price, and this impacts enterprises' behavior and decision-making by encouraging them towards green innovation. Furthermore, the adoption of carbon emission trading regulations helps to reduce financial barriers [54,55] and offers financial incentives to enterprises for the sale of carbon emission rights, in addition to improving the environmental responsibility of enterprises [56]. These benefits increase the enterprise's appeal to investors, which improves investment in green innovation and promotes the level of green innovation. The existing empirical literature has revealed that Hubei Province performed admirably in the carbon emission trading pilot and achieved a desirable low-carbon innovation effect. The success can be attributed to the selection of an auction mechanism as the initial quota allocation method and the implementation of strict regulatory measures in the carbon market [57].

However, as we mentioned above, some scholars argue that the impact of carbon emission trading policy on green innovation hinges crucially on the extent of "innovation offsets" as well as the influence of "compliance costs" [58–60]. Lanoie et al. [61] found that in the short term, environmental regulations can seem to impede technological innovation. However, in the long run, these regulations have a stimulating effect on innovation. Chen et al. [62] found that when enterprises are governed by government regulations and environmental guidelines, they have a lower motivation to participate in green innovation initiatives aimed at reducing carbon emissions.

The existing literature mainly focuses on the direct impact of carbon emission trading policies on green innovation, rarely being concerned with the effect from the perspective of the enterprise lifecycle. The relevant theories on the corporate lifecycle originate from organizational science in management. This theory suggests that the development pattern of a corporation hinges on the resources it possesses and the various opportunities it encounters during its growth process [63]. When enterprises are at different lifecycle stages, their size, financing capabilities, financial status, and other factors exhibit heterogeneity [26,64–66]. Research on how the corporate lifecycle currently influences business operations has garnered attention from scholars [67,68]. The impact of carbon emission trading policies varies among enterprises of different sizes, with different proportions of long-term debt, and within the industry with varying profit margins [69,70]. Therefore, it is worthwhile to delve into the effects of carbon emission trading policies on green innovation in enterprises at different lifecycle stages. When considering this perspective, some literature only treat it as a part of heterogeneity analysis [27,44]. This indicates that there is still a lack of research on the impact from the perspective of enterprise lifecycle. Therefore, this paper enhances the existing research by offering empirical insights into the impact of carbon emissions trading policies on green innovation, specifically from the perspective of enterprise lifecycle. Based on this foundation, we delve into its heterogeneity and the underlying impact mechanisms. By introducing the lifecycle theory, we can gain a more comprehensive understanding of the evolutionary process of how carbon trading policies influence corporate green innovation activities, and how these activities are affected by a corporation's current lifecycle stage.

There are three contributions. First, the paper introduces a unique perspective of the enterprise lifecycle to examine the relationship between carbon emission trading policy and corporate green innovation. By differentiating between the effects of the policy across the growth, maturity, and decline stages, it provides fresh insights into how firms' developmental stages influence their response to environmental regulations. Second, we conduct a comprehensive heterogeneity of enterprise scale, the proportion of independent directors, the level of green innovation and pilot regions. This multi-faceted approach reveals interesting variations in policy effectiveness across different subgroups, contributing to a more targeted and nuanced policy recommendation framework. Third, the paper identifies and analyzes two distinct influence mechanisms—financing constraints and capital investment—through which carbon emission trading policy affects green innovation. By demonstrating that these mechanisms operate differently across different lifecycle stages, the paper sheds light on the complex interplay between regulation, firm behavior, and the underlying economic conditions.

2.2. Hypotheses Development

2.2.1. The Impact of Carbon Emission Trading Policy on Green Innovation

The carbon emission trading mechanism is regarded as a market-oriented environmental regulation instrument [71]. The Porter hypothesis argues that implementing suitable environmental regulations can effectively stimulate technical innovation, leading to enhanced production efficiency and output quality [31]. For enterprises with large carbon emissions, the emission regulation department establishes carbon emission quotas and permits the market trading of carbon emission rights. Enterprises have to purchase carbon emission rights if their carbon emissions surpass the emission quotas. Enterprises that fail to complete their emission reduction tasks on time will suffer penalties such as fines and being placed on the dishonest list. This mechanism serves two purposes. Firstly, it intensifies the economic burden on high-carbon emissions-oriented enterprises, leading to higher costs associated with carbon emissions. Secondly, it creates a financial incentive for low-carbon emission enterprises, and they can make additional profits by selling the unused carbon emission rights [49]. This kind of incentive and punishment mechanism will incentivize enterprises to prioritize environmental sustainability and carbon emission reduction during their manufacturing processes. As a result, enterprises foster the adoption of green technology and encourage green innovation initiatives [17].

From the perspective of the enterprise lifecycle, entrepreneurs are typically confident during the stage of growth. Enterprises at the growth stage have strong innovation capabilities and a higher degree of cooperation with regulators. They are, therefore, more aggressive in employing green innovation technology to decrease the cost of carbon emissions and profit from carbon trading [28]. During the maturity stage, the company experiences an expansion in production scale and the operation becomes more efficient and effective [29]. The company is quite financially stable and places a higher priority on its long-term growth. Through active engagement in protecting the environment and the promotion of sustainable development, the company can cultivate a positive social reputation and proactively reduce compliance risks. In the decline stage, companies encounter significant constraints in financing, technology, and manpower, leading to a greater emphasis on survival, resulting in a lack of incentive for green innovation [28,30].

Hypothesis 1. *The carbon emission trading policy improves green innovation, and the effect on the enterprises at the growth and maturity stage is significant.*

2.2.2. The Influential Mechanism of Carbon Emission Trading Policy on Green Innovation

Enterprises involved in carbon emission trading have to annually reconcile their carbon emissions on the exchange. This policy incentivizes enterprises to prioritize enhancing the clarity and openness of environmental protection information. Thoroughly providing environmental protection information allows investors to obtain a more comprehensive understanding of how enterprises adopt technology to conserve energy, reduce emissions, utilize clean energy, and generate environmentally friendly products. Investor recognition of a company's technological application in this field will help improve the company's reputation and indirectly ease the fundraising process [72]. Enterprises will be in an advantageous position to obtain external funding if financing restrictions are reduced. This will help them improve the technology R&D efforts and strengthen the capacity for autonomous innovation [73].

Relatively speaking, enterprises in the growth stage have more financial restrictions. They are more likely to invest in projects that can swiftly increase the size of the market if the funding situation improves. Enterprises may be less likely to invest in green innovation projects due to the high risk and unclear benefits [74]. However, it is noteworthy that in China, with the continuous improvement of the green financial system, especially the introduction of green financial products such as green credit, green bonds, and green funds, more financing channels and lower financing costs have been provided for growth-stage enterprises to invest in green innovation projects [75,76]. These green financial instruments not only help enterprises solve funding problems but also guide capital flows to green areas through policy incentives and market mechanisms, promoting sustainable economic and social development [77–79]. Therefore, under China's unique green financial environment, growth-stage enterprises may not necessarily face severe financing constraints but have the potential to achieve a breakthrough [80]. In the mature stage, the enterprise has a high market share in its products and reaches a peak in profitability. Currently, businesses are inclined to preserve their market position. When the financing constraints are reduced, businesses may choose to participate in environmentally friendly innovation activities in order to sustain their competitive edge [81]. In the decline stage, companies may experience issues that will reduce market share. To improve their influence, these enterprises may choose perfunctory innovation [30].

Hypothesis 2. *The impact of financial constraint differs depending on the stage of an enterprise's lifecycle, and it has a significant effect on enterprises in the maturity stage.*

Hypothesis 3. *The impact of financial constraint differs depending on the stage of an enterprise's lifecycle, and it has a significant effect on enterprises in the growth stage and in the maturity stage.*

When enterprises are incorporated into the carbon emission trading system, they will put emphasis on environmental friendliness and sustainable development [69]. Carbon emission trading policies can enhance the environmental reputation and social accountability of enterprises [82]. According to Truong et al. [83], intangible assets have the ability to raise the value of businesses and strengthen their fundamental competitive advantages. Furthermore, when making decisions on long-term capital investments, enterprises are more likely to prioritize investments in environmental protection sectors, such as energy saving, emission reduction, and renewable energy [**Error! Reference source not found.**,84]. Energy-saving devices, wind turbines, solar panels, sewage treatment plants, and other associated structures are frequently purchased and installed as part of these investments in environmental preservation. In addition to promoting green technology innovation within enterprises, capital investment, especially intangible assets, can increase the technological caliber and goodwill value of enterprises [86].

For enterprises in the growth stage, the profit model and market basis have been preliminary established according to the theory of enterprise lifecycle. To support activities like capacity expansion and market expansion, they typically need a sizable sum of money. Encouraging green innovation is ineffective for enterprises in the growth stage because they may invest more capital for these reasons. However, with the increasing emphasis on environmental protection and sustainable development in society, the market demand for green products and services is also on the rise [87]. To satisfy this market demand and maintain a competitive edge, enterprises in their growth stage may opt to increase capital investment to drive green technological innovation. Enterprises in the mature stage are more likely to actively seek long-term development strategies to support the green upgrading of manufacturing processes since they have relatively substantial capital [88]. Relatively speaking, because of the unclear capital investment and inflexible internal procedures, enterprises in the decline stage, might not be as positive about green innovation [89].

Hypothesis 4. *The impact of capital investment differs depending on the stage of an enterprise's lifecycle, and it has a significant effect on enterprises in the maturity stage.*

Hypothesis 5. *The impact of capital investment differs depending on the stage of an enterprise's lifecycle, and it has a significant effect on enterprises in the growth stage and in the maturity stage.*

3. Research Methods and Data Sources

3.1. Research Methods

This paper examines how carbon emission trading regulations affect companies' efforts to innovate sustainably, from the perspective of enterprise lifecycle. This paper classifies the lifecycle of enterprises based on the cash flow patterns method and subsequently employs the DID model to explore the impact of carbon emissions trading policies on corporate green innovation. It explores the heterogeneity in enterprise-scale heterogeneity, the proportion of independent directors and the level of green innovation heterogeneity, and investigates the underlying influence mechanism. The process of method research is shown in Figure 1.

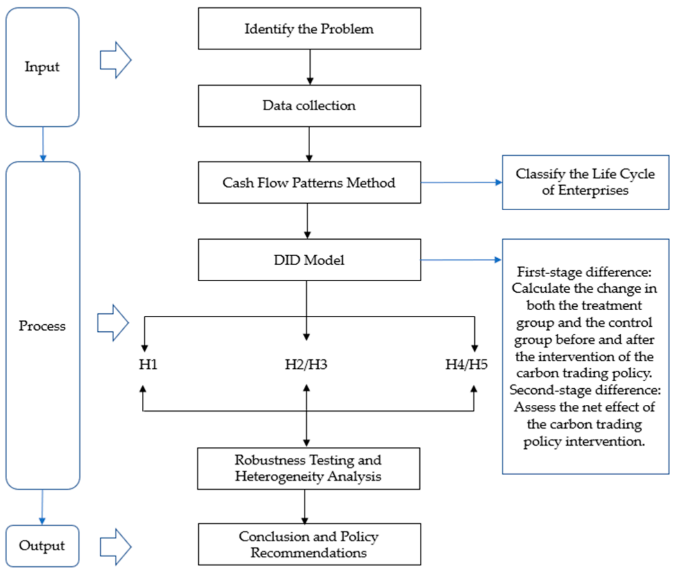

Figure 1. The process of method research.

3.1.1. Basic Regression Model

The construction of China's carbon emission trading pilot market is divided into three batches. However, many scholars mainly focus on the first two batches of pilots when studying the effectiveness of carbon emission trading policies, and empirical tests are conducted using 2013 or 2014 as the year of policy implementation to construct a single period difference in difference (DID) model. In addition to avoiding estimation bias caused by time inconsistency, the multi-period difference in difference method can be used to analyze the effects of policy shocks on individuals at different time points. This paper examines the impact of carbon emission trading policies on corporate green innovation by using a multi-period difference in difference model, and it takes 2013, 2014 and 2016 as the implementation time points of the policy. The model is as follows:

$$GIE_{it} = \alpha_0 + \alpha_1 DID_{it} + \alpha_2 Control_{it} + \delta_i + \mu_t + \varepsilon_{it} \tag{1}$$

where the subscript i stands for the observation unit, the subscript t stands for the time. *GIE* stands for the level of green innovation of the enterprise. *DID* is a dummy variable that equals 1 in the years after ETS is launched in enterprise, and 0 otherwise. The main explanatory variable coefficient α_1, shows that the carbon emission trading policy has a significant effect on green innovation if it is significantly positive. *Control* represents the control variables, δ represents individual fixed effects, μ represents year fixed effects, and ε stands for the standard errors.

3.1.2. The Method of Cash Flow Patterns

The existing research mostly applies three methods to classify the lifecycle of enterprises. The first method is the single variable analysis, which predominantly utilizes individual indicators, such as the growth rate of core business revenue, to evaluate the different stages of an enterprise's lifecycle. Secondly, Dickinson [90] proposes a method based on cash flow patterns, which analyzes the positive and negative combination of net cash flows generated from operating, financing, and investment activities to determine the lifecycle of a company. Furthermore, Anthony and Ramesh [91] employed the financial comprehensive indicator approach, assigning different weights to multiple indicators such as the growth rate of capital expenditure and the growth rate of the main business. They then computed the weighted average of these indicators to ascertain the enterprise's lifecycle stage. The cash flow patterns objectively reflect the business risks, profitability, and growth rate of a company through the positive and negative combinations of net cash flows from operating, investing, and financing activities. This method avoids the limitations of univariate analysis, which tends to be overly simplistic, and comprehensive indicator analysis, which tends to be highly subjective [84,92].

The three primary stages of an enterprise's lifecycle—growth, maturity, and decline—are discussed in this paper in relation to the cash flow grouping approach according to Dickinson [90]. Given the characteristics of Chinese listed companies, the start-up stage typically aligns with the stage of growth. Thus, this paper merges the two stages. During the growth stage, enterprises experience rapid growth and require substantial funds to support their expansion. Therefore, the net operating cash flow and net investment cash flow frequently demonstrate negative values. Fundraising activities act as the main way for enterprises to acquire capital, resulting in a positive net cash flow. When the enterprise is in the maturity stage, its market position is more stable and the net operating cash flow is positive. Companies prioritize capital returns and decrease investment activities. This leads to negative net cash flows from financing and investment. Nevertheless, when a company enters a recession, its market share may be affected by competitors, resulting in a decrease in operational efficiency and a negative net operating cash flow. Companies may participate in investment activities, such as selling fixed assets, to continue operations and achieve a positive net investment cash flow. Due to varying financial demands and business tactics, the net cash flow from fundraising may be positive or negative. Table 1 in this paper is established based on the analysis above, and the samples selected are categorized into lifecycles according to the criteria.

Table 1. Division criteria of lifecycle.

	Growth Period		Maturity Period	Decline Period				
	Startup Period	Growth Period		Fluctuation Period			Elimination Period	
Net operating cash flow	−	+	+	−	+	+	−	−
Net investment cash flow	−	−	−	−	+	+	+	+
Net financing cash flow	+	+	−	−	+	−	+	−

3.2. Variables and Data

3.2.1. Dependent Variable: Green Innovation

The level of green innovation is measured in this paper by the quantity of green patent applications. In contrast to R&D expenditure, the quantity of green patent applications can directly reflect the degree of importance that the company attaches to green technology innovation. Furthermore, the quantity of green patent applications has benefits above the quantity of green patent authorizations, including temporal sensitivity, reflecting the positive attitude of the enterprise and helping stakeholders to conduct preliminary evaluations. Current research has proposed various methods for measuring corporate green technology innovation, such as using the number of green patent grants [93], green patent applications [94], and green R&D investment [95] as indicators. In contrast to R&D expenditure, the quantity of green patent applications can directly reflect the degree of importance that the company attaches to green technology innovation due to a patent license needing to be detected and the need to pay an annual fee, and patent technology in the application period may affect enterprise performance. Furthermore, the quantity of green patent applications has benefits above the quantity of green patent authorizations, such as temporal sensitivity, reflecting the positive attitude of the enterprise and helping stakeholders to conduct preliminary evaluations. Compared to the method of using a comprehensive indicator to represent green innovation, the number of green patent applications offers clear quantifiability, and its data sources, such as the National Intellectual Property Administration, are highly authoritative and reliable. Furthermore, considering that the research objective of this paper is to explore the impact of external factors, such as carbon trading policies, on green innovation, using the number of green patent applications as a measurement indicator may be more appropriate. This indicator can directly reflect the response and changes of enterprises in terms of green technological innovation. However, if the research goal is to conduct a comprehensive and in-depth analysis and evaluation of green innovation, then constructing a comprehensive indicator may be more suitable. The level of green innovation is measured in this paper by the quantity of green patent applications [96].

3.2.2. Control Variables

Enterprise size (SIZE): The level of enterprise size is measured by the natural logarithm of the enterprise's total assets [97,98]. Compared to small-scale enterprises, complete organizational structures, market visibility, and financial strength possessed by large-scale enterprises contribute to green innovation.

Leveraged level (LEV): The paper employs the asset–liability ratio as an index to calculate the level of leverage [99,100]. A greater asset–liability ratio indicates that the enterprise is exposed to significant debt concerns, leading to severe liquidity issues and impeding the sustainable growth of the enterprise.

Ownership concentration (LHR): This paper selects the shareholding ratio of the largest shareholder of the enterprise as the proxy variable of ownership concentration [101].

High ownership concentrations frequently provide major shareholders greater control over decision-making, which may make it challenging for smaller shareholders to establish meaningful checks and balances against the major shareholders. The absence of diverse perspectives may restrict the ability of companies to develop and innovate, which could potentially impede their long-term, stable development.

Enterprise age (AGE): Enterprise age is calculated by the years of the listed companies [97]. It is widely accepted that enterprises are inclined to consolidate and enhance their competitive position through technological innovation, product upgrades and market expansion as the age of the enterprise increases.

Enterprise value (Q): We select the value of Tobin's Q to represent the enterprise value [98]. The value acts as an important indicator of market performance and the value of intangible assets. Typically, companies with higher values of Tobin's Q prioritize sustainable development performance to a greater extent.

Profitability (ROA): This paper selects return on assets as the proxy variable of profitability [99,100]. Return on assets reflects the level of business management and market competitiveness of enterprises and the capacity for enterprises to allocate additional resources towards environmentally friendly advancements.

The variable definitions are shown in Table 2.

Table 2. Variable definitions.

Variables	Symbols	Definitions	Data Source
Green innovation	GIE	Ln (Green patent applications + 1)	CNRDS database
Enterprise size	SIZE	Ln (Total assets)	CSMAR database
Leveraged level	LEV	Asset liability ratio	
Profitability	ROA	Return on assets	
Enterprise age	AGE	Ln (the reporting period year–the listing year)	
Enterprise value	Q	Tobin Q value	
Ownership concentration	LHR	The largest shareholder's shareholding ratio	

3.3. Data Source and Descriptive Statistics

This study specifically examines A-share listed businesses in China's Shanghai and Shenzhen stock markets. As per the information reported by the development and reform commissions of China's provinces and cities, the list of pilot enterprises is updated on a yearly basis, and these pilot enterprises may continue to change. In certain pilot zones, the list of pilot enterprises is not publicly available. The study examines eight industries with high CO2 emissions according to Liu and Zhang [**Error! Bookmark not defined.**], including non-ferrous metals, petrochemicals, and steel. The treated group includes industry enterprises with high CO2 emissions, while the control group comprises other enterprises in the pilot areas. Table 3 provides the list of industries with high carbon emissions. In order to ensure precision and efficiency, the samples are treated as follows: (1) excluding abnormal trading enterprises such as ST, ST* and PT; (2) excluding the particularity of the financial industry; (3) excluding the samples that lacked essential data and extremely abnormal data. This paper uses panel data for a total of 8892 observations from 2010 to 2022 in 684 enterprises of China. The data on green patent applications are obtained from the CNRDS database and the financial data utilized for the control variables is from the CSMAR database. In addition, to eliminate the impact of outliers on the regression results, the main continuous variables are tailed at 1% and 99% quantiles. Table 4 reports the descriptive statistics for all variables and Table 5 reports the descriptive statistics for the variables in the three enterprise lifecycles.

Table 3. The list of industries with high carbon emissions.

Industry	Code	Industry Name (Level 3)	Industry Name (Level 1)	Pilot Areas
Petrochemical industry	C25	Petroleum processing, coking, and nuclear fuel processing industries	Manufacturing	Shenzhen, Shanghai, Beijing, Guangdong, Tianjin, Hubei, Fujian
Chemical industry	C26	Chemical raw material and chemical product manufacturing industry		Shenzhen, Shanghai, Tianjin, Hubei, Chongqing, Fujian
Building material industry	C30	Non-metallic mineral products industry		Shenzhen, Guangdong, Hubei, Chongqing, Fujian
Steel industry	C31	Black metal smelting and rolling processing industry		Shenzhen, Shanghai, Guangdong, Tianjin, Hubei, Chongqing, Fujian
Nonferrous industry	C32	Non-ferrous metal smelting and rolling processing industry		Shenzhen, Shanghai, Hubei, Fujian
Papermaking industry	C22	Paper making and paper products industry		Shenzhen, Shanghai, Guangdong, Tianjin, Hubei, Chongqing, Fujian
Electric power industry	D44, D45	Production and supply of electricity, heat, and gas	Production and supply of electricity, heat, and gas	Shenzhen, Shanghai, Beijing, Guangdong, Tianjin, Hubei, Chongqing, Fujian
Aviation industry	G56	Air transport industry	Transportation, storage and postal services	Shenzhen, Shanghai, Beijing, Tianjin, Chongqing, Fujian

Table 4. Descriptive statistics.

Variable	Obs	Mean	Std	Min	Max	Median
GIE	8885	2.693	2.013	0.000	9.554	2.833
LEV	8885	0.462	0.213	0.049	0.935	0.470
ROA	8885	0.034	0.213	−6.776	10.400	0.033
SIZE	8885	8.791	1.564	3.124	14.820	8.584
AGE	8885	19.060	6.659	1.000	44.000	19.000
Q	8747	2.154	2.959	0.625	122.190	1.586
LHR	8800	0.346	0.157	0.078	0.738	0.321
SA	8885	3.815	0.316	2.737	4.492	3.838
CI	8872	0.291	0.201	0.008	0.826	0.250
GIE	8885	2.693	2.013	0.000	9.554	2.833

Table 5 shows the results of descriptive statistics at different stages of the enterprise lifecycle, including growth, maturity and decline. The mean degree of green innovation among enterprises in the growth, maturity, and decline stages is 2.933, 2.741, and 2.178, respectively. Enterprises in the stage of decline have significantly lower performance in green innovation compared to enterprises in other stages of the lifecycle. The standard deviations for the three stages of green innovation are 2.017, 2.012 and 1.912, respectively. Enterprises in the growth stage have a greater distribution of green innovation than enterprises in the maturity and decline stages.

Table 5. Descriptive statistics for different enterprise lifecycles.

Enterprise Lifecycle	Variable	Obs	Mean	St	Min	Max
Growth	GIE	3576	2.933	2.017	0.000	9.524
	LEV	3576	0.498	0.204	0.049	0.935
	ROA	3576	0.030	0.208	−0.201	10.401
	SIZE	3576	8.986	1.580	3.124	14.791
	AGE	3576	18.155	6.777	2.000	42.000
	Q	3520	1.915	1.777	0.706	56.664
	LHR	3543	0.339	0.152	0.079	0.738
Maturity	GIE	3332	2.741	2.012	0.000	9.554
	LEV	3332	0.422	0.210	0.049	0.935
	ROA	3332	0.045	0.101	−2.896	2.637
	SIZE	3332	8.804	1.597	3.826	14.821
	AGE	3332	19.045	6.657	1.000	41.000
	Q	3283	2.153	2.920	0.625	122.190
	LHR	3300	0.363	0.163	0.078	0.738
Decline	GIE	1977	2.178	1.912	0.000	9.420
	LEV	1983	0.463	0.222	0.049	0.935
	ROA	1977	0.022	0.329	−6.776	8.441
	SIZE	1977	8.418	1.402	3.716	14.478
	AGE	1977	20.726	6.107	3.000	44.000
	Q	1944	2.589	4.259	0.744	92.250
	LHR	1957	0.330	0.153	0.079	0.738

4. Results and Analysis

4.1. Analysis of Benchmark Regression Results

Table 6 presents the benchmark regression results of carbon emission trading policies on corporate green innovation. Individual-fixed effects, time-fixed effects, province year-fixed effects and industry year-fixed effects are controlled in columns (1)–(8). Columns (1) and (2) show the regression results for the whole sample. The estimated coefficients are positive and statistically significant at the 1% level. It indicates that carbon emission trading policies have a significant promoting effect on the green innovation of enterprises. Columns (3)–(4) and (5)–(6) show the regression results of enterprises in the growth stage and maturity stage, respectively. The regression coefficient of the DID variable is significantly positive, indicating a notable positive impact of carbon emission trading policies on green innovation in growth and maturity-stage enterprises. Columns (7) and (8) show the regression results of declining-stage enterprises. The coefficients are not significant, and the carbon trading policies have no impact on green innovation in the decline stage. Therefore, H1 is verified. This result demonstrates that the Porter effect is evident during the growth and maturity stages of enterprises, whereas carbon trading policies do not function as an incentive mechanism during the decline stage of enterprises. This finding aligns with Liu et al. (2022) and Jia et al. (2024) [27,44].

Table 6. Benchmark regression results.

Variable	(1) GIE	(2) GIE	(3) GIE	(4) GIE	(5) GIE	(6) GIE	(7) GIE	(8) GIE
DID	0.262 ***	0.278 ***	0.209 **	0.263 ***	0.266 ***	0.211 **	−0.001	−0.127
	(4.42)	(4.59)	(2.22)	(2.72)	(2.77)	(2.15)	(−0.00)	(−0.58)
LEV		−0.196 **		−0.162		0.116		−0.757 ***
		(−2.01)		(−1.01)		(0.61)		(−3.25)
ROA		−0.182		−0.401		−0.423		−0.529
		(−0.89)		(−1.08)		(−1.09)		(−1.29)
SIZE		0.512 ***		0.518 ***		0.501 ***		0.376 ***
		(20.99)		(12.17)		(10.88)		(6.16)
AGE		−0.021		−0.014		−0.022		0.023
		(−0.58)		(−0.22)		(−0.32)		(0.29)
Q		0.017		0.056 ***		0.022		−0.037
		(1.57)		(2.63)		(1.21)		(−1.41)
LHR		−0.004 ***		−0.005 **		0.001		−0.005
		(−2.73)		(−2.12)		(0.35)		(−1.30)
_cons	2.370 ***	−1.167 **	2.032 ***	−1.934 *	3.352 ***	−0.673	2.013 ***	0.520
	(10.60)	(−2.02)	(3.95)	(−1.82)	(6.68)	(−0.63)	(4.83)	(0.39)
Firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pro × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	8885	8665	3576	3488	3332	3251	1977	1926
R2	0.242	0.289	0.313	0.349	0.240	0.282	0.162	0.210

Note: T values are shown in brackets; ***, **, * indicates statistical significance at 1%, 5%, and 10% levels, respectively.

4.2. Robustness Testing

4.2.1. Parallel Trend Hypothesis Testing

Figure 2 illustrates the changes in GIE before and after the implementation of the policy in 2013, 2014 and 2016. It was found that before the implementation of carbon emission trading policies, there was no systematic difference in the GIE among industry enterprises with high CO2 emissions and other enterprises in the pilot areas. Following the implementation of the carbon trading policies, treated groups' GIE significantly increased and remained higher than controls. However, in 2017, treated groups' GIE values were similar due to the launch of the national carbon market, which reduced enterprises' motivation for carbon reduction and green innovation.

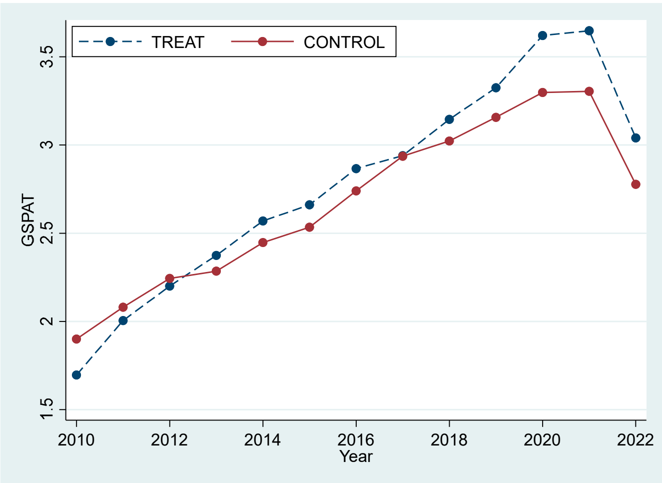

Figure 2. Trend in GIE of the treatment and control groups.

Figure 3 shows the results of the event study method of the impact of carbon emission trading policies on green innovation. Before the implementation of carbon emission trading policies, the regression coefficients did not differ significantly from zero at the 95% confidence interval. After the implementation of carbon trading policies, the coefficients have been significantly positive since 2018, indicating a lag effect on green innovation.

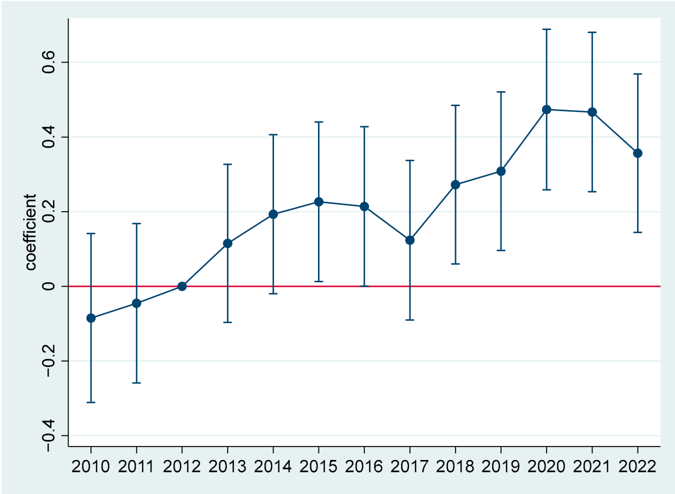

Figure 3. Parallel trend hypothesis testing.

4.2.2. Placebo Test

We used a placebo test based on Ferrara et al. [103] to identify the contingency of the impact of the carbon emission trading policies on green innovation by generating "false policy" through 500 random selections in order to remove the interference of non-observable factors on the research conclusion. This paper randomly constructs a treated group and empirically tests the new sample. We drew a regression coefficient distribution chart. As shown in Figures 4–7, the estimated coefficient distribution of the placebo test is concentrated around 0, which is close to the normal distribution. This indicates that the positive effect of carbon emission trading policies on green innovation in enterprises is not caused by random factors or sample selection bias. The results of benchmark regression are robust.

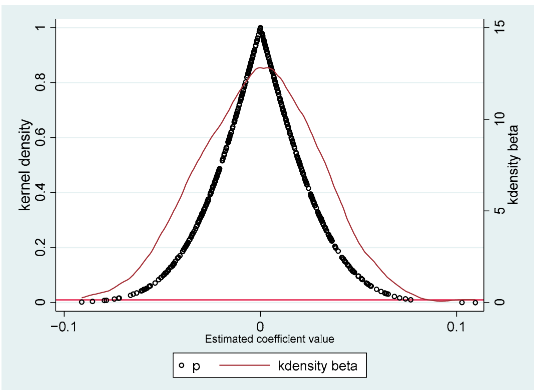

Figure 4. Placebo test (whole sample).

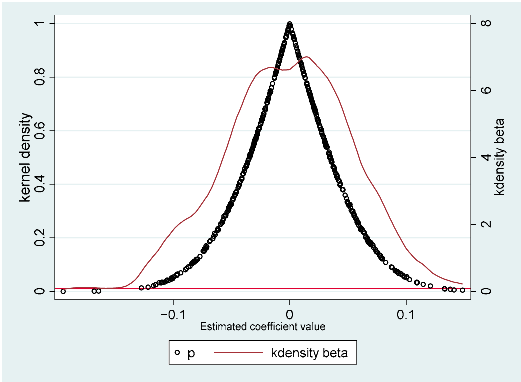

Figure 5. Placebo test (growth stage).

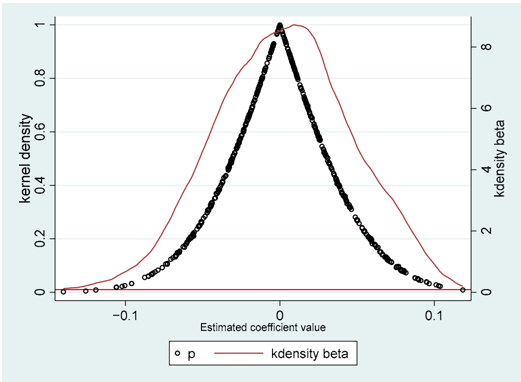

Figure 6. Placebo test (maturity stage).

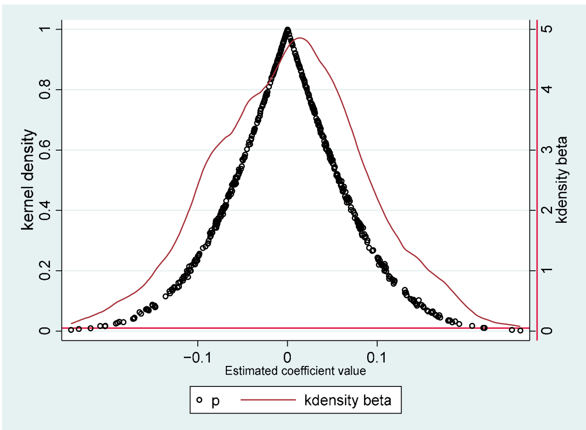

Figure 7. Placebo test (declining stage).

4.2.3. Entropy Balance Matching Method

As the covariate differences between the treatment group and the control group are difficult to manage using the DID method, we use the entropy balance matching method to eliminate estimation bias and improve the robustness of policy evaluation following Hainmuller [104]. The first-order moments of green innovation are used as constraints for year-by-year matching. To lessen sample selection bias, we computed entropy-balanced weight values, which brought the weighted control and experimental groups closer together in each covariate. Table 7 shows the regression results. Columns (1)–(4) show the regression result for the entire lifecycle growth stage, maturity stage and decline stage, respectively. The regression coefficients in columns (1)-(3) remain significantly positive and the coefficient in column (4) is not significant. It verifies the benchmark regression results.

Table 7. The regression results of entropy balance matching method.

Variable	(1) GIE	(2) GIE	(3) GIE	(4) GIE
DID	0.230 ***	0.204 ***	0.148 **	−0.082
	(5.69)	(3.07)	(2.14)	(−0.74)
LEV	−0.083	−0.529 ***	0.174	0.203
	(−0.78)	(−2.95)	(0.84)	(0.86)
ROA	−0.176	−0.845 **	−0.409	0.496
	(−0.84)	(−2.12)	(−1.06)	(1.27)
SIZE	0.441 ***	0.367 ***	0.464 ***	0.275 ***
	(17.01)	(7.89)	(9.74)	(4.63)
AGE	0.004	−0.036	−0.057	0.014
	(0.11)	(−0.49)	(−0.41)	(0.25)
Q	0.026 *	0.005	0.052 **	−0.016
	(1.83)	(0.17)	(2.03)	(−0.54)
LHR	0.002	−0.002	0.008 ***	−0.008 *
	(1.29)	(−0.80)	(3.07)	(−1.80)
_cons	−1.435 *	0.500	−0.755	−0.195
	(−1.75)	(0.35)	(−0.27)	(−0.16)
Firm	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Pro × Year	Yes	Yes	Yes	Yes
Ind × Year	Yes	Yes	Yes	Yes
N	8665	3452	3206	1807
R2	0.833	0.847	0.875	0.873

Note: T values are shown in brackets; ***, **, * indicates statistical significance at 1%, 5%, and 10% levels, respectively.

4.2.4. Eliminating Policy Interference

To eliminate the potential impact of the implementation of the new Environmental Protection Law's in 2015, we construct the policy dummy variable for 2015 and subsequent years in the model. As shown in Table 8, columns (1)–(4) represent the regression results of the entire lifecycle, growth stage, maturity stage and decline stage, respectively. The coefficients of DID in columns (1)–(3) are significantly positive and the coefficient is not significant in column (4). It verifies the benchmark regression results.

Table 8. The regression results of eliminating policy interference.

Variable	(1) GIE	(2) GIE	(3) GIE	(4) GIE
DID	0.278 ***	0.263 ***	0.211 **	−0.127
	(4.59)	(2.72)	(2.15)	(−0.58)
LEV	−0.196 **	−0.162	0.116	−0.757 ***
	(−2.01)	(−1.01)	(0.61)	(−3.25)
ROA	−0.182	−0.401	−0.423	−0.529
	(−0.89)	(−1.08)	(−1.09)	(−1.29)
SIZE	0.512 ***	0.518 ***	0.501 ***	0.376 ***
	(20.99)	(12.17)	(10.88)	(6.16)
AGE	−0.021	−0.014	−0.022	0.023
	(−0.58)	(−0.22)	(−0.32)	(0.29)
Q	0.017	0.056 ***	0.022	−0.037
	(1.57)	(2.63)	(1.21)	(−1.41)

LHR	−0.004 ***	−0.005 **	0.001	−0.005
	(−2.73)	(−2.12)	(0.35)	(−1.30)
POL	0.176	0.221	−0.067	−0.898
	(0.38)	(0.26)	(−0.08)	(−0.88)
_cons	−1.167 **	−1.934 *	−0.673	0.520
	(−2.02)	(−1.82)	(−0.63)	(0.39)
Firm	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Pro × Year	Yes	Yes	Yes	Yes
Ind × Year	Yes	Yes	Yes	Yes
N	8665	3488	3251	1926
R2	0.289	0.349	0.282	0.210

Note: T values are shown in brackets; ***, **, * indicates statistical significance at 1%, 5%, and 10% levels, respectively.

4.2.5. Replacing the Implementation Time of the Policy

The carbon emission trading markets in Beijing, Guangdong, Shanghai, and Tianjin were officially opened at the end of 2013, and the carbon market in Fujian was opened at the end of 2016. This paper adjusts their implementation years to 2014 for Beijing, Guangdong, Shanghai, and Tianjin, and to 2017 for Fujian, through regression analysis. The results are displayed in Table 9. Columns (1)–(4) represent the regression results of the entire lifecycle, growth stage, maturity stage and decline stage, respectively. The regression results validate the conclusions of the basic regression.

Table 9. The regression results of replacing the implementation time of the policy.

Variable	(1) GIE	(2) GIE	(3) GIE	(4) GIE
DID	0.265 ***	0.240 **	0.254 ***	−0.056
	(4.69)	(2.57)	(2.85)	(−0.28)
LEV	−0.199 **	−0.161	0.120	−0.750 ***
	(−2.04)	(−1.00)	(0.63)	(−3.23)
ROA	−0.195	−0.408	−0.461	−0.534
	(−0.96)	(−1.09)	(−1.19)	(−1.30)
SIZE	0.512 ***	0.517 ***	0.501 ***	0.376 ***
	(21.00)	(12.13)	(10.89)	(6.15)
AGE	−0.023	−0.014	−0.022	0.024
	(−0.63)	(−0.20)	(−0.32)	(0.31)
Q	0.017	0.056 ***	0.023	−0.037
	(1.58)	(2.64)	(1.24)	(−1.41)
LHR	−0.004 ***	−0.005 **	0.001	−0.005
	(−2.68)	(−2.09)	(0.35)	(−1.30)
_cons	−1.147 **	−1.937 *	−0.681	0.500
	(−1.99)	(−1.82)	(−0.64)	(0.38)
Firm	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Pro × Year	Yes	Yes	Yes	Yes
Ind × Year	Yes	Yes	Yes	Yes
N	8665	3488	3251	1926
R2	0.290	0.349	0.283	0.210

Note: T values are shown in brackets; ***, **, * indicates statistical significance at 1%, 5%, and 10% levels, respectively.

4.3. Heterogeneity Analysis

4.3.1. Enterprise Scale Heterogeneity

Enterprises vary in scale, which may lead to heterogeneous impacts of the carbon emission trading policy on green innovation. We divide the whole sample into two groups, large-scale enterprises and small-scale enterprises, according to the median of total assets. Table 10 shows the regression results. For large enterprises (Cols. 1–4), DID coefficients are significantly positive in the full lifecycle and growth stage but not in maturity or decline. This suggests they invest in green innovation during growth for reputation and carbon market profits. For small enterprises (Cols. 5–8), the DID coefficients are significantly positive in the full lifecycle and maturity stage. They focus on market share and revenue growth during growth, then invest in green innovation when capital is sufficient.

Table 10. The regression results of enterprise scale heterogeneity.

	Large-Scale Enterprises				**Small-Scale Enterprises**			
Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
DID	0.419 ***	0.467 ***	0.194	−0.520	0.147 *	−0.055	0.270 *	−0.101
	(4.60)	(3.29)	(1.39)	(−1.09)	(1.71)	(−0.37)	(1.74)	(−0.36)
LEV	−0.332 *	−0.150	0.093	−1.288 **	−0.015	0.166	0.237	−0.517 *
	(−1.72)	(−0.48)	(0.27)	(−2.03)	(−0.12)	(0.76)	(0.88)	(−1.87)
ROA	0.554	0.408	0.961	−0.768	−0.479 **	−0.729	−0.736	−0.320
	(1.38)	(0.59)	(1.34)	(−0.66)	(−2.05)	(−1.58)	(−1.47)	(−0.72)
SIZE	0.460 ***	0.354 ***	0.484 ***	0.485 ***	0.550 ***	0.642 ***	0.423 ***	0.507 ***
	(9.52)	(4.53)	(5.43)	(3.19)	(12.18)	(7.62)	(4.63)	(4.73)
AGE	0.010	0.003	0.018	0.116	−0.101	−0.070	−0.180	−0.066
	(0.20)	(0.03)	(0.21)	(0.63)	(−1.53)	(−0.48)	(−1.22)	(−0.57)
Q	−0.040	0.079	−0.056	−0.219 **	0.009	0.058 **	−0.003	−0.035
	(−1.45)	(1.48)	(−1.38)	(−2.07)	(0.67)	(2.09)	(−0.14)	(−1.14)
LHR	−0.002	−0.001	0.001	−0.006	0.003	0.002	0.004	0.003
	(−1.03)	(−0.31)	(0.27)	(−0.96)	(1.10)	(0.48)	(0.86)	(0.47)
_cons	−2.594 ***	−2.061	−3.379	−2.600	−0.562	−1.980	1.255	0.912
	(−2.84)	(−1.39)	(−1.34)	(−0.82)	(−0.58)	(−0.96)	(0.61)	(0.48)
Firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pro × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	4371	1946	1637	788	4294	1542	1614	1138
R2	0.294	0.329	0.330	0.292	0.240	0.282	0.162	0.210

Note: T values are shown in brackets; ***, **, * indicates statistical significance at 1%, 5%, and 10% levels, respectively.

4.3.2. The Proportion of Independent Directors Heterogeneity

The strengthened oversight capability of independent directors has the potential to influence the execution of green innovation initiatives. This paper categorizes samples into high and low independent director proportions to estimate carbon trading policies impact on green innovation. Table 11 shows the results. For large enterprises with high proportions (Cols. 1–4), the DID coefficients are positive in full lifecycle and maturity. For those with low proportions (Cols. 5–8), coefficients are positive in full lifecycle and growth. It indicates that enterprises with a high proportion of independent directors tend to adopt more rational measures in response to the impact of carbon emission trading policies.

Table 11. The regression results of the proportion of independent director heterogeneity.

	High Proportion of Independent Directors				Low Proportion of Independent Directors			
Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
DID	0.281 ***	−0.015	0.406 **	0.332	0.344 ***	0.563 ***	0.229	−0.264
	(2.89)	(−0.10)	(2.46)	(0.54)	(4.10)	(3.84)	(1.63)	(−0.92)
LEV	−0.431 ***	−0.829 ***	0.272	−0.826 **	0.136	0.409	0.431	−0.678 *
	(−3.02)	(−3.55)	(0.83)	(−2.48)	(0.93)	(1.61)	(1.56)	(−1.69)
ROA	−0.239	−0.536	0.220	−0.374	−0.325	−0.562	−0.513	−0.808
	(−0.87)	(−0.98)	(0.37)	(−0.70)	(−1.03)	(−0.96)	(−0.85)	(−1.02)
SIZE	0.554 ***	0.503 ***	0.517 ***	0.336 ***	0.450 ***	0.529 ***	0.448 ***	0.375 ***
	(15.11)	(7.78)	(6.52)	(3.84)	(12.05)	(7.62)	(6.73)	(3.39)
AGE	−0.077	−0.074	−0.077	0.059	0.022	0.052	−0.027	0.051
	(−1.48)	(−0.99)	(−0.47)	(0.47)	(0.36)	(0.35)	(−0.28)	(0.37)
Q	0.005	0.053 *	−0.022	−0.051	0.049 ***	0.085 **	0.081 ***	−0.037
	(0.35)	(1.79)	(−0.83)	(−1.46)	(2.82)	(2.57)	(2.77)	(−0.80)
LHR	−0.001	−0.001	−0.003	−0.001	−0.008 ***	−0.013 ***	0.004	−0.018 ***
	(−0.67)	(−0.16)	(−0.69)	(−0.17)	(−3.45)	(−3.02)	(1.03)	(−2.65)
_cons	−0.820	−2.053	−1.023	1.414	−1.814 *	−2.923	−1.290	−1.793
	(−1.00)	(−1.42)	(−0.45)	(0.70)	(−1.92)	(−1.38)	(−0.90)	(−0.75)
Firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pro × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	4429	1806	1620	1003	4236	1682	1631	923
R2	0.161	0.095	−0.084	−0.283	0.161	0.060	−0.027	−0.301

Note: T values are shown in brackets; ***, **, * indicates statistical significance at 1%, 5%, and 10% levels, respectively.

4.3.3. The Level of Green Innovation Heterogeneity

Differences in the level of green innovation affect the strategies that enterprises adopt in response to the implementation of carbon emission policies. We divide the whole sample into two groups, high-level of green innovation and low-level of green innovation, according to the median of green innovation. Table 12 shows the regression results. Columns (1)-(4) show results for high-level green innovation across the full lifecycle, growth, maturity, and decline periods. Columns (5)-(8) present similar results for low-level green innovation. Notably, in the maturity stage of high-level green innovation, the DID coefficients are significantly negative, suggesting that carbon trading policies reduce green innovation. On one hand, carbon emission policies may alter enterprises' future policy expectations, making them believe policies are stringent or further innovation offers little short-term returns. On the other hand, high-level green innovators may face higher costs and risks, discouraging further investment. In contrast, for low-level green innovation, carbon trading policies improve green innovation, but DID coefficients are insignificant across the growth, maturity, and decline stages due to enterprise heterogeneity in resources, technology, and management.

Table 12. The regression results of the level of green innovation heterogeneity.

	High-Level of Green Innovation				Low Proportion of Independent Directors			
Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
DID	−0.062	−0.009	−0.218 **	0.040	0.232 ***	0.134	0.198	−0.255
	(−1.01)	(−0.09)	(−2.23)	(0.14)	(3.13)	(1.02)	(1.62)	(−1.13)
LEV	−0.266 ***	−0.457 ***	−0.378 *	−0.552 *	−0.091	−0.287	0.366	−0.358
	(−2.59)	(−2.70)	(−1.93)	(−1.76)	(−0.83)	(−1.44)	(1.51)	(−1.53)
ROA	0.052	−0.045	0.048	−0.099	−0.490 **	−0.997 **	−0.618	0.106
	(0.26)	(−0.13)	(0.12)	(−0.20)	(−2.12)	(−2.04)	(−1.33)	(0.25)
SIZE	0.477 ***	0.468 ***	0.424 ***	0.484 ***	0.160 ***	0.203 ***	0.115 *	0.095
	(18.30)	(10.94)	(8.29)	(5.48)	(5.42)	(3.58)	(1.88)	(1.51)
AGE	−0.082 ***	−0.065	0.021	−0.103	−0.010	0.071	−0.050	−0.030
	(−2.74)	(−1.35)	(0.36)	(−1.03)	(−0.17)	(0.40)	(−0.53)	(−0.31)
Q	0.031 ***	0.041 **	0.047 **	0.064	−0.008	0.018	−0.009	−0.018
	(2.67)	(2.03)	(2.47)	(1.58)	(−0.67)	(0.66)	(−0.40)	(−0.67)
LHR	−0.003 **	−0.008 ***	0.002	−0.003	−0.001	−0.000	0.003	−0.005
	(−2.31)	(−3.41)	(0.73)	(−0.62)	(−0.81)	(−0.13)	(0.80)	(−1.24)
_cons	−0.126	0.931	−1.988	1.174	0.055	−1.460	0.742	2.402
	(−0.20)	(0.98)	(−1.22)	(0.76)	(0.06)	(−0.58)	(0.50)	(1.45)
Firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pro × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	4376	1949	1662	765	4289	1539	1589	1161
R2	0.343	0.416	0.371	0.363	0.096	0.142	0.116	0.102

Note: T values are shown in brackets; ***, **, * indicates statistical significance at 1%, 5%, and 10% levels, respectively.

4.3.4. Regional Heterogeneity

To clarify the impact of carbon emission trading policies in pilot regions on green innovation, this paper conducted a regression analysis on eight pilot regions, respectively. The results are shown in Table 13. In the regression results of each region, the first column is the regression result of the whole lifecycle, and the second to fourth columns are the regression results of the growth stage, the mature stage and the decline stage, respectively. According to Table 13, Shenzhen and Beijing's carbon emissions trading policies have a significant positive impact on enterprises throughout their entire lifecycle and particularly in the growth stage. Guangdong's policy, meanwhile, positively affects the green innovations of enterprises in the maturity stage. Conversely, Hubei's policy has a significant negative effect on the green innovation in the growth stage, potentially due to institutional constraints like the expiration and cancellation of untraded carbon quotas. Chongqing's policy, on the other hand, has no significant impact, primarily because of excessive total carbon quotas. Tianjin and Fujian's policies positively influence enterprises in the growth stage but Tianjin's policy also negatively impacts those in the decline stage. Lastly, Shanghai's policy shows no significant impact, which may be attributed to its weak legal status as a mayor's order and uneven quota allocation across different industries.

Table 13. The regression results of regional heterogeneity.

Variable	**Shenzhen**				**Beijing**			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
DID	0.449 **	0.453 *	0.295	−0.604	0.869 ***	0.879 ***	0.384	0.679
	(2.56)	(1.72)	(1.13)	(−0.57)	(5.97)	(4.18)	(1.19)	(0.89)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Variable	**Guangdong**				**Hubei**			
	(9)	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**	**(15)**	**(16)**
DID	0.282 **	−0.051	0.559 **	0.155	0.166	−0.536 *	0.118	0.113
	(1.96)	(−0.24)	(2.22)	(0.18)	(0.17)	(−1.75)	(0.31)	(0.13)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Variable	**Chongqing**				**Fujian**			
	(17)	**(18)**	**(19)**	**(20)**	**(21)**	**(22)**	**(23)**	**(24)**
DID	0.472	0.282	−0.045	−0.139	0.217	0.533 **	0.209	0.431
	(1.58)	(0.53)	(−0.07)	(−0.11)	(1.38)	(2.07)	(0.72)	(0.84)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Variable	**Tianjin**				**Shanghai**			
	(25)	**(26)**	**(27)**	**(28)**	**(29)**	**(30)**	**(31)**	**(32)**
DID	0.296	1.448 **	−0.125	−0.911 *	−0.076	−0.132	0.018	−0.369
	(0.79)	(2.17)	(−0.22)	(−1.84)	(−0.49)	(−0.45)	(0.08)	(−0.83)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ind × Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: T values are shown in brackets; ***, **, * indicates statistical significance at 1%, 5%, and 10% levels, respectively.

4.4. Mechanism Verification

4.4.1. Model Setting

Based on the theoretical and hypothetical sections mentioned above, we select financing constraints (SA) and corporate capital (CI) investment as intermediary variables to explore the mechanism of carbon emission trading policies on corporate green innovation. The construction of the mediation model is described as follows

$$M_{it} = \beta_0 + \beta_1 DID_{it} + \beta_2 Control_{it} + \delta_1 + \mu_t + \varepsilon_{it} \quad (2)$$

$$GSPAT_{it} = \gamma_0 + \gamma_1 DID_{it} + \gamma_2 M_{it} + \gamma_3 Control_{it} + \delta_i + \mu_t + \varepsilon_{it} \quad (3)$$

where the subscript i stands for the observation unit, the subscript t stands for the time. M stands for the mediating variables, including financing constraint SA and capital investment CI. We select the SA index to represent financing constraints, and the formula is SA = 0.043 × size^2−.737 × size−0.04 × age. Generally, the SA index takes a negative value, and the higher the SA value is, the greater the degree of financing constraints for the enterprise. The variable of capital investment is represented by the proportion of intangible assets, fixed assets, and other long-term assets in the total assets of the enterprise. The data are from the CSMAR database.

4.4.2. Verification of the Mechanism of Financing Constraint

Table 14 presents the empirical results of the carbon emissions trading policy affecting green innovation through financing constraints. Column (1) shows the impact of the carbon trading policy on financing constraints of the entire lifecycle of the enterprises. The DID coefficient is negative and significant at the 10% level, indicating that the policy is conducive to alleviating corporate financing constraints. In column (2), the DID coefficient is positive and significant, and the value is smaller than the DID coefficient in the benchmark regression, while the value of SA is negatively significant, indicating the existence of a mediating effect. Specifically, the carbon trading policy can promote green innovation by alleviating financing constraints. Columns (3)–(4) and columns (5)–(6) reflect the impact of the carbon trading policy on growing enterprises and mature enterprises, respectively. According to the regression results, the explanatory variables are significant and the signs are consistent with those of the whole sample. The mediating effect of financing constraints holds for growing enterprises and mature enterprises. Since there is no correlation between the green innovation of declining enterprises and the carbon trading policy, no further test of the mechanism is conducted. Hypothesis 3 is verified.

Table 14. The mechanism of financing constraint.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Variable	**SA**	**GIE**	**SA**	**GIE**	**SA**	**GIE**
DID	−0.023 ***	0.269 ***	−0.019 **	0.255 ***	−0.032 ***	0.196 **
	(−4.58)	(4.43)	(−2.22)	(2.63)	(−4.38)	(1.99)
LEV	0.040 ***	−0.180 *	0.058 ***	−0.137	0.048 ***	0.139
	(4.91)	(−1.85)	(4.02)	(−0.85)	(3.37)	(0.73)
ROA	0.050 ***	−0.163	0.019	−0.393	0.091 ***	−0.380
	(2.95)	(−0.80)	(0.57)	(−1.05)	(3.17)	(−0.98)
SIZE	−0.019 ***	0.504 ***	−0.024 ***	0.508 ***	−0.012 ***	0.495 ***
	(−9.14)	(20.59)	(−6.28)	(11.85)	(−3.53)	(10.74)
AGE	0.031 ***	−0.009	0.025 ***	−0.004	0.027 ***	−0.009
	(10.23)	(−0.24)	(4.24)	(−0.05)	(5.38)	(−0.14)
Q	−0.019 ***	0.010	−0.018 ***	0.048 **	−0.015 ***	0.015
	(−21.18)	(0.85)	(−9.55)	(2.23)	(−10.73)	(0.82)
LHR	−0.001 ***	−0.004 ***	−0.001 ***	−0.006 **	−0.001 ***	0.001
	(−6.44)	(−2.93)	(−4.50)	(−2.29)	(−3.40)	(0.23)
SA		−0.394 ***		−0.427 **		−0.468 *
		(−2.92)		(−2.03)		(−1.76)
_cons	3.402 ***	0.172	3.318 ***	−0.516	3.584 ***	1.003
	(70.79)	(0.23)	(34.69)	(−0.41)	(45.20)	(0.70)
Firm	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Pro × Year	Yes	Yes	Yes	Yes	Yes	Yes
Ind × Year	Yes	Yes	Yes	Yes	Yes	Yes
N	8665	8665	3488	348	3251	3251
R2	0.790	0.225	0.685	0.185	0.821	0.082

Note: T values are shown in brackets; ***, **, * indicates statistical significance at 1%, 5%, and 10% levels, respectively.

4.4.3. Verification of the Mechanism of Capital Investment

Table 15 presents the empirical results with enterprise capital investment as the mediating variable. Columns (1) and (2) show the policy effect of the implementation of the carbon trading policy on enterprise green innovation through increased capital investment in the full sample. The DID coefficient in column (1) is not significant, indicating that the carbon trading policy has no impact on enterprise capital investment. The carbon trading policy has not promoted green innovation by increasing capital investment. Columns (3) and (4) reflect the impact of growing enterprises through capital investment. According to the results, the mediating effect of enterprise capital investment is not valid for growing enterprises. Columns (5) and (6) reflect the impact of capital investment in mature enterprises. The regression coefficients of DID are significantly positive. This indicates that the mechanism of the carbon trading policy promoting green innovation by increasing capital investment in mature enterprises is valid. Hypothesis 4 is verified.

Table 15. The mechanism of capital investment.

Variable	(1) CI	(2) GIE	(3) CI	(4) GIE	(5) CI	(6) GIE
DID	0.020	0.265 ***	−0.003	0.266 ***	0.018 *	0.199 **
	(1.48)	(4.38)	(−0.34)	(2.76)	(1.78)	(2.03)
LEV	0.067 ***	−0.251 **	0.087 ***	−0.267 *	0.072 ***	0.070
	(3.08)	(−2.57)	(5.06)	(−1.66)	(3.71)	(0.37)
ROA	−0.048	−0.145	−0.045	−0.357	−0.031	−0.385
	(−1.47)	(−0.71)	(−1.12)	(−0.96)	(−0.79)	(−0.99)
SIZE	−0.018 ***	0.525 ***	−0.026 ***	0.547 ***	−0.009 *	0.506 ***
	(−2.86)	(21.50)	(−5.73)	(12.82)	(−1.92)	(11.00)
AGE	−0.016 **	−0.013	−0.009	−0.006	−0.015 **	−0.013
	(−2.38)	(−0.34)	(−1.25)	(−0.10)	(−2.24)	(−0.20)
Q	0.002	0.015	0.004	0.051 **	−0.001	0.021
	(0.81)	(1.39)	(1.59)	(2.42)	(−0.45)	(1.11)
LHR	−0.000	−0.004 **	−0.001 **	−0.005 *	0.000	0.001
	(−0.59)	(−2.52)	(−2.00)	(−1.83)	(1.28)	(0.35)
CI		0.644 ***		1.006 ***		0.622 ***
		(6.21)		(5.69)		(3.20)
_cons	0.685 ***	−1.616 ***	0.654 ***	−2.630 **	0.590 ***	−1.037
	(6.24)	(−2.78)	(5.76)	(−2.47)	(5.44)	(−0.97)
Firm	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Pro × Year	Yes	Yes	Yes	Yes	Yes	Yes
Ind × Year	Yes	Yes	Yes	Yes	Yes	Yes
N	8652	8652	3483	3483	3246	3246
R2	0.055	0.293	0.066	0.356	0.078	0.285

Note: T values are shown in brackets; ***, **, * indicates statistical significance at 1%, 5%, and 10% levels, respectively.

5. Conclusions and Policy Recommendations

5.1. Conclusions

We explore the impact of carbon emission trading policy on the level of green innovation in enterprises based on a sample of 684 A-share listed companies in the Shanghai and Shenzhen carbon market pilot areas from 2020 to 2022 from the perspective of the lifecycle, as well as its underlying mechanisms. The main conclusions are listed as follows: First, carbon emission trading policies significantly promote corporate green innovation, especially in the growth and the maturity stages of enterprises. Second, carbon trading policies vary by firm size, board independence, green innovation level, and region, with mixed impacts across enterprise lifecycle stages. Third, carbon emission trading policies influence green innovation in enterprises through financing constraints and capital investment, especially during the maturity stage.

5.2. Policy Recommendations

Based on the conclusions, we propose the policy implications. First, for growing and mature enterprises, the government should provide more flexible carbon emission trading policies to encourage them to conduct green innovation. For declining enterprises, the government can guide them to adapt to the new market environment through transformation or reorganization.

Second, full consideration of firm size, board independence and green innovation level disparities should be undertaken. Government should introduce incentive carbon trading policies for large growing firms and small mature firms, encourage high-director firms and high-innovation firms to invest in green innovation during the maturity stages of enterprises. Meanwhile, government should guide low-director firms to improve governance and provide more technical support for low-innovation firms, tailoring carbon trading policies to enterprises in different stages of lifecycle in pilot regions.

Third, the government should focus on the financing needs of enterprises in the growth stage and encourage them to increase green innovation investment by providing innovative financial products such as green credit and green bonds to reduce their financing costs. For enterprises in the mature stage, the government can also encourage them to increase capital investment in green innovation projects through tax incentives and fiscal subsidies.

5.3. Limitations and Future Directions

Despite being the first comprehensive exploration of the impact of carbon emission trading policies on corporate green innovation from a lifecycle perspective, this paper still has some limitations that require further research. Firstly, due to the typical characteristics of China's low-carbon policies, this paper only analyzes the effects of China's carbon trading policies. Therefore, subsequent research will attempt to assess the impact of carbon emission trading policies on corporate green innovation from a lifecycle perspective by combining data from different countries with Chinese data. Secondly, corporate green innovation in this paper is only represented by the number of green patent applications, which is a relatively single dimension of measurement. Moreover, patent applications usually require a certain time period, resulting in the number of green patent applications not reflecting current corporate green innovation activities in a timely manner. The next goal of this research is to comprehensively measure the level of corporate green innovation, taking into account multiple dimensions such as technological innovation and practical application.

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