The Influence of Carbon Emissions Trading Pilot Policies on Supply Chain Risks. -- A Quasi-Natural Experiment Based on A-Share Listed Companies

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Abstract. As a crucial measure for achieving the "dual carbon" goals, carbon emissions trading pilot policies have garnered widespread attention. This study analyzed the impact of carbon emissions trading pilot policies on corporate supply chain risk levels and their underlying mechanisms, using data from A-share listed companies from 2008 to 2021. The findings revealed that carbon emissions trading pilot policies significantly mitigate supply chain risks, and this conclusion remained valid after undergoing parallel trend tests, placebo tests, and PSM-DID analyses. Further analysis indicated that the mitigating effect is more pronounced among state-owned enterprises, large-scale firms, and companies located in eastern China. Mechanism analysis suggested that Carbon Emissions Trading Pilot Policies reduces supply chain risks by promoting technological innovation, enhancing corporate development quality, and improving industrial structures. The conclusions of this study provide valuable insights for firms to leverage carbon policies for supply chain risk management and achieve sustainable development.

Keywords: Carbon Emissions Trading Pilot Policies, Supply Chain Risk Level, Technological Innovation, High-Quality Corporate Development, Industrial Structure.

1. Introduction

Under the background of green development, environmental concerns have garnered increasing attention. Climate warming poses significant threats to human life and societal progress. Therefore, making the reduction of greenhouse gas emissions is an urgent global task. China has demonstrated its wisdom and commitment by proposing carbon peak by 2030 and carbon neutrality by 2060, followed by the implementation of carbon emissions trading pilot policies in eight provinces and municipalities (Beijing, Tianjin, Shanghai, Guangdong, Shenzhen, Hubei, Chongqing, and Fujian) in 2013. As a market-based environmental policy tool, carbon emissions trading pilot policies have strong marketization and flexibility, serving as an effective pathway for driving low-carbon transitions among numerous enterprises (Li et al., 2023). Thus, these policies are not only advantageous for sustainable corporate development but also crucial for addressing national environmental challenges.

Previous studies have explored the impact of carbon emissions trading pilot policies on corporate behavior. For instance, Zhao Zhenzhi and Feng Yiqi (2023) found that carbon emissions trading effectively curbs corporate tax avoidance. Liu Kaihao et al. (2023) observed a significant increase in corporate export propensity under these policies. Li Jianjun (2024) noted the policies improved information disclosure among firms. However, the influence of carbon emissions trading pilot policies on corporate supply chain risk levels remains underexplored.

Theoretically, as a market-oriented environmental policy tool, carbon emissions trading pilot policies aim to incentivize firms to reduce emissions economically, thereby promoting low-carbon transitions and green development, which in turn lower corporate supply chain risks. Empirical evidence supported the ideas that these policies enhance corporate ESG performance (Yang and Zhang, 2023), boost firm value (Xu et al., 2024), increase stock liquidity (Wang and Gu, 2024), and elevate stock returns (Hu et al., 2023). All of these indicated that carbon emissions trading pilot policies can enhance a company's position and value in the market. Other enterprises are more inclined to collaborate with companies that have implemented carbon emissions trading pilot policies.

As a result, these implementing companies can establish long-term cooperative relationships with upstream and downstream enterprises, increase their bargaining power within the supply chain, and reduce various risks and uncertainties faced by the company, thereby lowering the overall supply chain risks.

Nevertheless, carbon emissions trading pilot policies may also lead to a mismatch between innovation conditions and policy requirements for some enterprises, resulting in an increase in their supply chain risk levels. To adapt to carbon emissions trading policies, companies will shift their focus towards carbon reduction-related activities. On one hand, enterprises will invest additional human, material, and financial resources in green technological innovations aimed at reducing emissions, building upon their existing operations (Liu et al., 2023). Under such circumstances, corporate costs will rise significantly. Since enterprises require a certain amount of capital reserves to manage and control their supply chains, an increase in costs will correspondingly reduce these reserves, thereby heightening the risk of unresolved existing issues within the supply chain. On the other hand, some regulated enterprises, if lacking sufficient emission reduction capabilities, may resort to fabricating carbon emissions data or underreporting their emissions to avoid the costs associated with purchasing additional carbon emission allowances (Zhang et al., 2024). Such behaviors not only mislead society's perception of the true state of carbon emissions but also lead to biases in the public's understanding of these enterprises' information. These factors will ultimately contribute to an elevation in the enterprise's supply chain risk levels. Furthermore, information asymmetry is another factor that can trigger supply chain risks. If an increasing number of enterprises attempt to tamper with carbon emissions data, it will exacerbate information risks throughout the entire supply chain system.

Therefore, the direction of the impact of carbon emissions trading pilot policies on enterprise supply chain risk levels remains uncertain and requires empirical testing to determine its effect. This study utilized data from A-share listed companies from 2008 to 2021 to demonstrate that carbon emissions trading pilot policies have a significant suppressive effect on enterprise supply chain risk levels. This conclusion remains valid after parallel trend tests, placebo effects, and PSM-DID estimations. Heterogeneity analysis revealed that this effect is more pronounced in state-owned enterprises, large-scale enterprises, and enterprises located in the eastern region of the country. Mechanism analysis indicates that carbon emissions contribute to reducing supply chain risks by strengthening enterprises' low-carbon technological innovation, promoting high-quality corporate development, and facilitating corporate energy transformation. Therefore, the findings of this study prove that carbon emissions trading pilot policies are conducive to lowering enterprise supply chain risk levels, providing valuable references for enterprises to respond to carbon market mechanisms and enhance their low-carbon transitions.

The marginal contributions of this paper are as follows: Firstly, this study conducts research from an economic perspective, expanding the research domain of carbon emissions trading pilot policies. Existing literature predominantly focuses on the direct assessment of the emission reduction effects of carbon trading pilot policies, such as empirical studies demonstrating that China's carbon emissions trading pilots have achieved positive results in promoting simultaneous reductions in both total and intensity of carbon emissions, as well as accelerating the development of a low-carbon society (Chen, 2022). This paper explored how carbon emissions trading policies can reduce enterprise supply chain risks by promoting corporate innovation, enhancing the quality of corporate development, and optimizing industrial structures, thereby addressing theoretical limitations in the intersection of carbon emissions trading pilot policies and enterprise supply chain risks. Secondly, this paper initiates research from the enterprise perspective, broadening the scope of economic research on carbon emissions trading pilot policies. Current literature tends to focus on the impact of these policies at the provincial and municipal levels in China, such as studying their effects on regional green innovation efficiency (Xiao et al., 2022) and the economic quality of cities at and above the prefecture level (Shao and Li, 2022). However, there is relatively less attention paid to the enterprise level. Therefore, this paper took enterprises as the research object, enriching the impact scope of carbon emissions trading pilot policies. Thirdly, it provides policy optimization paths for enterprise supply chain risk management under the "dual carbon" goals. The establishment of enterprise supply chains aims to reduce the costs of providing goods and generate certain profits (Dang, 2003). Nevertheless, supply chains also entail certain risks. An increase in supply chain risks not only negatively impacts the economy of enterprises but may even lead to supply chain "disruptions", causing severe blows to enterprises. This paper investigated the mechanisms through which carbon emissions trading pilot policies reduce enterprise supply chain risk levels, offering references for enterprises to better cope with and mitigate supply chain risks.

The structure of this paper is as follows: The first section is introduction, the second section presented a literature review, the third section outlined research hypotheses and empirical design, the fourth section conducted benchmark regression analysis, the fifth section performed robustness tests, the sixth section carried out heterogeneity tests, the seventh section analyzed mechanisms, and the eighth section provided conclusions and policy recommendations.

2. Literature Review

2.1. Research on Carbon Emissions Trading Pilot Policies

Carbon emissions trading policies, drawing on the experience of the European carbon emissions trading system, aim to achieve emission reduction targets by setting a total amount on carbon emissions and allowing enterprises to trade emission allowances. Previous studies have demonstrated that carbon trading pilot policies can effectively promote carbon emission reductions in public buildings (Zhu et al., 2025), significantly curbing the growth of carbon emissions in pilot regions (Zhang et al., 2021) and lowering carbon emission intensity in pilot areas, showcasing notable carbon reduction effects (Cheng and Yang, 2023). Furthermore, Sun Zhenqing et al. (2020) pointed out that carbon trading policies not only facilitate emission reductions in pilot regions but also promote coordinated reductions in non-pilot regions.

In addition, carbon trading policies have also influenced the economic sphere. At the macro level, the implementation of carbon market policies can alleviate the increase in green supply chain financial risks (Peng, 2024) and foster green economic growth (Liao et al., 2020). Wang Zhao et al. (2019) also found that carbon emissions trading systems significantly reduce the opportunity costs of urban emission reductions. At the micro level, numerous scholars have discovered that carbon emissions trading pilot policies can promote corporate green innovation (Xiao et al., 2023; Chen et al., 2022), including both the quantity and quality of innovation (Hu et al., 2020). Moreover, these policies can substantially increase corporate cash holdings (Zhang and Yang, 2022), weaken financing constraints (Wen and Qin, 2021), promote industrial structure transformation and upgrading (Zhang et al., 2023), and ultimately improve corporate financial performance (Lin and Zhao, 2022).

2.2. Research on Supply Chain Risks

Supply chain risks, as potential threats, can cause significant harm to supply chains (Liu et al., 2006). An increase in supply chain risks can reduce the efficiency and increase the costs of the entire supply chain, ultimately affecting the actual benefits received by supply chain enterprises. A review of existing literature revealed that research on supply chain risks can be generally divided into studies on internal and external factors influencing supply chains. Internal factors arise within the supply chain due to incomplete collaboration among supply chain members (Zhu et al., 2006) and primarily include management risks (Zhao, 2023), moral hazards (Zhang et al., 2001), information risks (Dang, 2003), and cooperation risks (Zhang, 2007). External factors stem from the macro environment and subsequently affect the industry environment and supply chain enterprises (Wang and Li, 2011), including natural environmental risks (Yu t al., 2024), political and legal risks (Liu et al., 2006), and market risks (Li and Chen, 2003).

Management risks refer to the increased uncertainty in supply chain management due to the conflicting goals of supply chains pursuing overall benefits and enterprises pursuing their own interests, making supply chain management more challenging (Wang and Li, 2011). Moral hazards arise when supply chain partner enterprises exhibit a tendency to evade responsibilities and remain inactive, violating commitments and engaging in "shirking" behavior. This unethical conduct undermines trust among supply chain enterprises, making supply chain operations more difficult (Zhang et al., 2001). Information risks refer to information asymmetry and incompleteness among enterprises within the same supply chain. Information sharing enables real-time responses to any issues within the supply chain and fosters trust among enterprises. However, each enterprise acts rationally and considers its own interests, leading them to withhold some information as business secrets. This lack of information sharing with upstream and downstream enterprises results in poor information flow within the supply chain, affecting its operational efficiency (Dang, 2003). Cooperation risks arise when partner enterprises do not cooperate or cooperate inadequately. Apart from contracts and agreements, there are no mandatory constraints among supply chain member enterprises, making it difficult to bring all enterprises together to work collaboratively. Furthermore, variations in technological, financial, and cultural levels among enterprises can lead to unequal statuses within the supply chain, with lower-status enterprises receiving fewer benefits. This reduces the enthusiasm of some enterprises to cooperate, resulting in inadequate cooperation. A lack of cooperation or inadequate cooperation increases the response and action times of supply chain member enterprises to market changes, reducing their flexibility (Zhang, 2007). Natural environmental risks primarily refer to natural disasters, including floods, earthquakes, and other irresistible natural calamities. The occurrence of such events can disrupt or even sever supply chains, posing significant threats. Political and legal risks refer to the uncertainties brought about by changes in politics and laws. In today's rapidly developing era, the pace of policy and legal changes has significantly increased, introducing uncertainties to supply chains. Additionally, political unrest and wars can further exacerbate these risks. Market risks refer to the deviation of products from customer needs, resulting in unpopular products in the market and difficulty in realizing their value. This leads to enterprises being unable to collect revenue from product sales, potentially causing supply chain funding disruptions (Li and Chen, 2003).

It is evident that scholars have conducted in-depth research on the operational effects of carbon emissions trading pilot policies and the influencing factors of supply chain risks. Carbon emissions trading pilot policies, in driving the emission reduction process, have had various impacts on different aspects of the economy, with the majority of these impacts being positive. Meanwhile, due to their inherent vulnerability, supply chains can have negative effects on enterprises. A comprehensive review of existing research revealed that, despite studies on carbon emissions trading pilot policies touching on the economic sphere, the research scope remains relatively narrow. Specifically, there is a lack of in-depth exploration into the impact of these policies on enterprise supply chain risks level. Furthermore, current literature predominantly examines the impact of carbon emissions trading pilot policies at the macro level, focusing on their effects on Chinese provincial and municipal regions, while paying relatively less attention to their micro-level impacts. Therefore, building upon existing research, this paper investigates the relationship between carbon emissions trading policies and enterprise supply chain risks level from an enterprise perspective, making certain contributions to both theoretical and practical aspects.

3. Research Hypotheses and Empirical Design

3.1. Research Hypotheses

The carbon emissions trading pilot policies internalize pollution costs (Hao et al., 2024), thereby significantly increasing environmental cost pressures on enterprises in supply chain management. To avoid the high costs associated with supply chain risks, enterprises may adopt the following behaviors:

Firstly, enterprises may increase investment in carbon emission reduction technologies. These technological investments can promote the innovative development of carbon reduction technologies (Fan et al., 2017), optimize products, and green production processes. These carbon emission reduction technologies can not only enhance resource utilization efficiency and production efficiency to lower carbon emissions (Luo et al., 2024) but also reduce the costs of purchasing additional carbon emission allowances (Liu and Zhang, 2017), and even enable the sale of a portion of the company's carbon emission allowances to alleviate environmental cost pressures.

Secondly, enterprises may adjust their industrial structures to cope with the restrictions on carbon emission allowances. The implementation of carbon trading policies serves as a reminder to enterprises that high-energy-consuming enterprises will be the first to be eliminated, while low-energy-consuming enterprises will receive attention and development (Zhou and Liu, 2020). To keep pace with the latest societal trends, enterprises must minimize their energy consumption, making industrial structure adjustment the preferred method for reducing carbon emissions. By transitioning from high-energy-consuming and high-polluting industries to low-carbon tertiary industries, enterprises can effectively reduce carbon emission intensity and avoid the risk of elimination.

Finally, enterprises may be driven by market demand (Liu et al., 2019) to transform and reduce environmental costs through corporate restructuring. Green consumption has become a consensus among most consumers, who increasingly prioritize green and resource-efficient products when making purchases. The market's demand for low-energy-consuming products is rising. If the sales end of the supply chain continues to focus on selling high-energy-consuming products, it may lead to product inventory buildup, resulting in uncollectible accounts receivable (Wang, 2022). Therefore, enterprises will introduce products that meet green demands to the market based on consumer demand, thereby achieving higher returns while reducing carbon emissions.

The aforementioned behaviors play a significant role in reducing carbon emissions and, concurrently, lower supply chain risk levels. The development of emission reduction technologies is conducive to stabilizing and promoting corporate economic growth, ensuring stable supply chain funding. Adjusting the industrial structure enables long-term stable development of enterprises, thereby reducing the risk of supply chain disruption. Market-driven and incentivized transformations can lower market risks in corporate supply chains. Therefore, this paper proposes the following research hypothesis H1:

H1: The carbon emissions trading pilot policies can significantly reduce corporate supply chain risk levels.

3.2. Empirical Design

To verify the hypothesis, this paper sets up a Difference-in-Differences (DID) model following the research of Liu Qiren et al. (2024). The model is as follows:

$$Bullwhip_{it} = \alpha_0 + \alpha_1 Treat\_Post_{it} + \alpha_3 Controls_{it} + \sum Year + \sum Firm + \varepsilon_{it} \tag{1}$$

The $Bullwhip_{it}$ in model measures the level of corporate supply chain risk. Following Liu Qiren et al. (2024), this paper used the deviation between enterprise production fluctuations and demand fluctuations to measure this indicator, where a higher value indicates a higher level of corporate supply chain risk and vice versa. The specific calculation method is as follows:

$$Bullwhip_{it} = \frac{\sigma(Production_{it})}{\sigma(Demand_{it})} = \frac{\text{Quarterly standard deviation of enterprise production volume}}{\text{Quarterly standard deviation of enterprise demand}} \tag{2}$$

Where the quarterly production volume is the sum of quarterly sales costs and quarterly inventory net value, and quarterly demand is the quarterly sales volume, which is the sum of main business income and other business income. Additionally, both quarterly production volume and quarterly demand undergo logarithmic transformation and first-order differencing before calculating the standard deviation.

The model treated $Treat\_Post_{it}$ as the interaction term ($Treat_i * Post_t$) between a regional dummy variable ($Treat_i$) and a time dummy variable ($Post_t$), following the research of Bian

Zhiqiang and Zhong Shunchang (2023). Furthermore, the periods before and after policy implementation ($Post_t$) are assigned values of 0 and 1, respectively. The variable $Treat_i$ indicates whether an enterprise has implemented a carbon emissions trading pilot policies, with a value of 1 if the enterprise is located in a carbon emissions trading pilot city and 0 otherwise. The regression results should focus on the estimated coefficient α_2. If the estimated value is significantly negative, it indicates that the carbon emissions trading pilot policies have reduced corporate supply chain risk levels, thereby validating the hypothesis of this paper.

The $Controls_{it}$ in the model is a series of control variables, including company size ($Size$), asset-liability ratio (Lev), return on total assets (ROA), ownership concentration of the top ten shareholders ($Top10$), equity nature (SOE), number of directors ($Board$), proportion of independent directors ($Indep$), whether audited by one of the Big Four accounting firms ($Big4$), duality of the chairman and CEO ($Dual$), and revenue growth rate ($Growth$). This paper controls for both year and enterprise fixed effects, with ε_{it} representing the random disturbance term in the model to account for unexplained factors. Additionally, to address potential cross-sectional heteroskedasticity issues, all regression models in this paper are adjusted for robust standard errors clustered by industry. The detailed definitions of the variables are shown in Table 1.

Table 1. Variable Definitions and Constructions

Variable Symbol	Variable Name	Variable Construction Description
$Bullwhip$	Corporate Supply Chain Risk Level	Deviation between enterprise production fluctuations and demand fluctuations
$Treat\_Post$	Policy Interaction Term	Interaction term between regional dummy variable and time dummy variable
$Size$	Total Assets	Total assets at the end of the year
Lev	Asset-Liability Ratio	Ratio of total liabilities to total assets
ROA	Return on Total Assets	Net profit / average total assets
$Top10$	Ownership Concentration of Top Ten Shareholders	Total shareholding of the top ten shareholders / total share capital
SOE	Equity Nature	1 for state-owned enterprises, 0 otherwise
$Board$	Number of Directors	Number of Directors Number of board members
$Indep$	Proportion of Independent Directors	Number of independent directors / total number of board members
$Big4$	Whether Audited by One of the Big Four Accounting Firms	Audited by Big Four 1 if audited by one of the Big Four accounting firms, 0 otherwise
$Dual$	Duality of the Chairman and CEO	Duality of Chairman and CEO 1 if the chairman and CEO are the same person, 0 otherwise
$Growth$	Revenue Growth Rate	(Current year's revenue - previous year's revenue) / previous year's revenue

3.3. Data Sources

This paper used data from A-share listed companies from 2008 to 2021 as the initial sample. After excluding samples from the financial and insurance industries, samples of ST and PT companies, and samples with missing data, the final experimental sample consists of 30,505 company-year observations. Relevant data are sourced from the CSMAR and Wind databases.

3.4. Descriptive Statistics

Descriptive statistics for the main variables are shown in Table 2. The mean value of the supply chain risk level (Bullwhip) is 0.597, with a standard deviation of 0.25, indicating significant fluctuations in supply chain risks among enterprises and unstable risks. The mean value of Treat_Post is 0.294, suggesting that approximately 30% of the companies implemented carbon emissions trading pilot policies during the selected time period. Its standard deviation is approximately 0.46, indicating significant differences among companies in implementing carbon emissions trading pilot policies.

Table 2. Descriptive Statistics

	(1)	(2)	(3)	(4)	(5)
Variable	Sample Size	Mean	Standard Deviation	Minimum Value	Maximum Value
Bullwhip	30,505	0.597	0.251	0.036	3.342
Treat_Post	30,505	0.294	0.456	0	1
Size	30,505	22.120	1.287	19.410	26.400
Lev	30,505	0.428	0.207	0.027	0.925
ROA	30,505	0.042	0.065	-0.375	0.245
Growth	30,505	0.166	0.404	-0.648	3.705
Board	30,505	2.137	0.199	1.609	2.708
Indep	30,505	0.374	0.054	0.250	0.600
Dual	30,505	0.257	0.437	0	1
Top10	30,505	0.585	0.153	0.210	0.910
SOE	30,505	0.381	0.486	0	1
Big4	30,505	0.059	0.236	0	1

3.5. Benchmark Regression Analysis

The benchmark regression results are presented in Table 3, where columns (1) to (4) represent scenarios without adding bidirectional fixed effects and control variables, only adding bidirectional fixed effects, only adding control variables, and adding both bidirectional fixed effects and control variables, respectively. The results indicate that, regardless of whether control variables and fixed effects are included, the coefficient of *Treat_Post* is significantly negative at least at the 5% confidence level. This demonstrates that the carbon emissions trading policy indeed suppresses corporate supply chain risks, validating Hypothesis H1.

Table 3. Benchmark Regression Results

	(1)	(2)	(3)	(4)
Variable	*Bullwhip*	*Bullwhip*	*Bullwhip*	*Bullwhip*
Treat_Post	-0.029***	-0.014**	-0.028***	-0.017***
	(-4.976)	(-2.449)	(-4.841)	(-2.988)
Size			0.003	0.007**
			(0.831)	(2.479)
Lev			-0.052***	0.016
			(-2.642)	(0.949)
ROA			0.189***	0.202***
			(4.748)	(5.439)
Growth			0.009*	0.011**
			(1.928)	(2.268)
Board			0.042**	-0.015
			(2.197)	(-1.005)
Indep			-0.033	-0.061
			(-0.525)	(-1.154)
Dual			-0.007	-0.009
			(-1.196)	(-1.619)
Top10			0.085***	0.067***
			(3.987)	(3.748)
SOE			0.036***	0.008
			(4.410)	(1.244)
Big4			0.041***	0.031***
			(2.601)	(2.743)
Constant	0.605***	0.571***	0.413***	0.421***
	(151.989)	(18.925)	(4.846)	(5.442)
Observations	30,505	30,505	30,488	30,488
R-squared	0.003	0.181	0.023	0.191
Firm FE	NO	YES	NO	YES
Year FE	NO	YES	NO	YES

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively; t-values are in parentheses. The same applies below.

4. Robustness Analysis

The regression results presented in this study are derived under ideal model conditions and may possess a certain degree of contingency. To control for this issue, this paper employs parallel trend tests, placebo tests, and PSM-DID methods to conduct robustness analyses.

4.1. Parallel Trend Test

A key prerequisite for using the multi-period DID model is ensuring that the experimental and control groups exhibit similar trends before the policy implementation, which means satisfying the parallel trend assumption. Therefore, this paper adopts the event study method to construct dummy variables for each period and incorporates them into the econometric model along with the core independent variable. Based on the regression results, the estimated coefficients are plotted year by year, as shown in Figure 1. Before the implementation of the carbon emissions trading pilot policy, the trends of the experimental and control groups were largely consistent, with coefficients fluctuating around zero. In the initial stages of policy implementation, the differences between the two groups were not significant, but after three to four years, the trends began to diverge markedly. This indicates a lagged effect of the carbon emissions trading pilot policy on supply chain risk levels. The reasons for this lag may include: (1) the need for policy transmission time, as companies require time to deeply interpret and learn the policy, analyze its integration with their own development, and adjust their internal supply chains before the policy can be fully implemented; (2) enterprise decision-making is often constrained by insufficient knowledge and information (Wu and Zhu, 2016). Initially, companies may lack sufficient understanding of the carbon emissions trading pilot policy and require time to collect relevant carbon emission information, thus delaying the policy's effect.

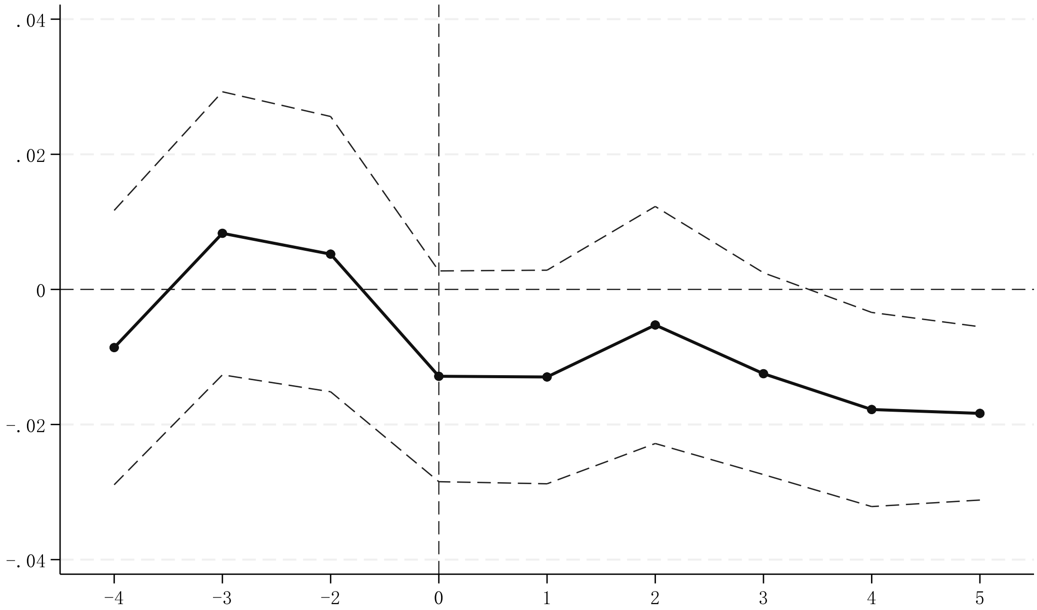

Figure 1. Parallel Trend Test

4.2. Placebo Test

This paper conducts a regression analysis using randomly generated "pseudo-policy dummy variables" in equal proportions and repeats the experiment 1,000 times to plot the empirical distribution function. As shown in the figure, most of the estimated coefficient’s cluster around zero and follow a normal distribution. Furthermore, the vast majority of p-values are above 0.1, indicating non-significance at the 10% level. Therefore, the regression results obtained in the previous sections pass the placebo test.

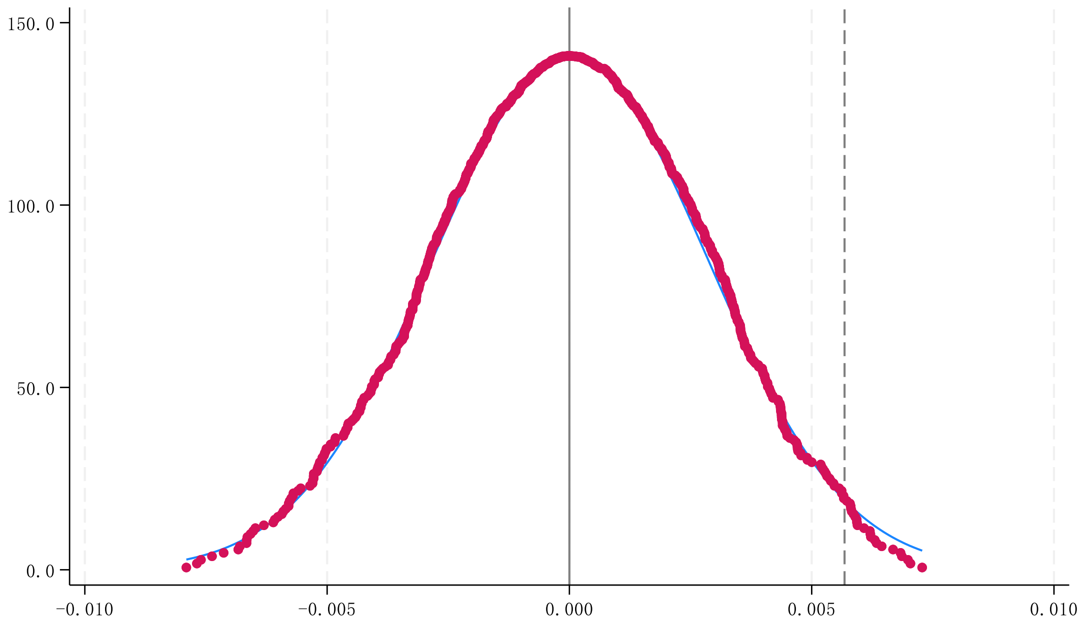

Figure 2. Placebo Test

4.3. PSM-DID

To address potential sample self-selection bias between the experimental and control groups, this paper employs the PSM-DID model for testing. Using a 1:1 nearest-neighbor matching approach, the experimental and control groups are matched, and samples that fail to match successfully are excluded before re-running the regression. The results show that under the PSM-DID model, the impact of the carbon emissions trading pilot policy on corporate supply chain risk levels remains significantly negative, indicating the robustness of the previous benchmark regression results.

Table 4. PSM-DID Results

	(1)	(2)	(3)	(4)
Variable	*Bullwhip*	*Bullwhip*	*Bullwhip*	*Bullwhip*
Treat_Post	-0.026***	-0.010*	-0.026***	-0.012**
	(-4.213)	(-1.725)	(-4.301)	(-2.013)
Size			0.003	0.008**
			(0.744)	(2.560)
Lev			-0.064***	0.018
			(-3.049)	(1.012)
ROA			0.149***	0.178***
			(3.523)	(4.432)
Growth			0.009	0.011**
			(1.530)	(1.993)
Board			0.030	-0.023
			(1.440)	(-1.345)
Indep			-0.047	-0.087
			(-0.682)	(-1.524)
Dual			-0.009	-0.009
			(-1.335)	(-1.516)
Top10			0.088***	0.058***
			(3.785)	(3.071)
SOE			0.034***	0.006
			(3.664)	(0.851)
Big4			0.039**	0.031**
			(2.316)	(2.564)
Constant	0.602***	0.593***	0.449***	0.457***
	(135.165)	(15.211)	(4.703)	(5.195)
Observations	19,754	19,754	19,754	19,754
R-squared	0.003	0.197	0.023	0.208
Firm FE	NO	YES	NO	YES
Year FE	NO	YES	NO	YES

5. Heterogeneity Analysis

5.1. Heterogeneity in Enterprise Ownership

The nature of enterprise ownership significantly influences a company's ability to cope with supply chain risks. State-owned enterprises often have access to richer government support and resource allocation (Zhang et al., 2022). For instance, in China, state-controlled companies typically find it easier to secure loans from state-owned banks, providing them with more substantial financial reserves to effectively manage supply chain risks. In contrast, non-state-controlled companies generally face financing difficulties (Xu and Wang, 2017), and often struggle to adequately respond to supply chain risks when they arise due to a lack of funds. Based on this, it can be hypothesized that under the carbon emissions trading pilot policies, SOEs will be more effective in reducing supply chain risk levels.

From Table 5, it can be seen that the carbon emissions trading pilot policies significantly reduce the supply chain risk levels of SOEs. However, for non-SOEs, although the coefficient is negative, it is not statistically significant. This indicates that compared to non-SOEs, SOEs are more effective in reducing supply chain risk levels under the carbon emissions trading pilot policies, validating the aforementioned hypothesis.

Table 5. Heterogeneity Analysis Results by Enterprise Ownership

	SOEs	Non-SOEs
Variable	*Bullwhip*	*Bullwhip*
Treat_Post	-0.030***	-0.010
	(-2.934)	(-1.481)
Size	0.007	0.010**
	(1.499)	(2.540)
Lev	-0.005	0.018
	(-0.188)	(0.881)
ROA	0.137*	0.224***
	(1.746)	(5.455)
Growth	0.012*	0.011
	(1.762)	(1.629)
Board	-0.017	-0.012
	(-0.749)	(-0.578)
Indep	-0.039	-0.046
	(-0.511)	(-0.645)
Dual	-0.008	-0.010
	(-0.646)	(-1.627)
Top10	0.034	0.089***
	(1.067)	(4.121)
Big4	0.039**	0.020
	(2.493)	(1.210)
Constant	0.469***	0.333***
	(4.015)	(3.296)
Observations	11,620	18,868
R-squared	0.287	0.125
Firm FE	YES	YES
Year FE	YES	YES

5.2. Heterogeneity in Enterprise Size

Compared to smaller enterprises, larger enterprises generally have advantages in terms of capital, technology, and talent, making them more capable of managing risks and ensuring supply chain stability when faced with supply chain shocks (Hu et al., 2020). Therefore, this paper hypothesizes that the carbon emissions trading pilot policies will have a more pronounced inhibitory effect on supply chain risk levels in larger enterprises.

Based on whether the enterprise size is greater than the average enterprise size, this paper divided the sample into large-scale and small-scale enterprises. The regression results reported in Table 6 show that the policy has a negative impact on supply chain risk levels for both large-scale and small-scale enterprises, but the coefficient for large-scale enterprises is significant at the 1% level, while that for small-scale enterprises is only significant at the 10% level. This demonstrates that the carbon emissions trading pilot policies have a stronger inhibitory effect on supply chain risk levels in large-scale enterprises, validating the aforementioned hypothesis.

Table 6. Heterogeneity Analysis Results by Enterprise Size

	Large-scale Enterprises	Small-scale Enterprises
Variable	*Bullwhip*	*Bullwhip*
Treat_Post	-0.022***	-0.012*
	(-2.690)	(-1.676)
Size	0.006	-0.007
	(1.239)	(-1.152)
Lev	0.040*	0.001
	(1.657)	(0.023)
ROA	0.190***	0.236***
	(3.400)	(5.108)
Growth	0.022***	0.002
	(3.329)	(0.299)
Board	-0.023	0.004
	(-1.152)	(0.177)
Indep	-0.129*	0.054
	(-1.844)	(0.735)
Dual	-0.010	-0.006
	(-1.194)	(-0.915)
Top10	0.090***	0.050**
	(3.778)	(2.069)
SOE	0.008	0.001
	(0.876)	(0.100)
Big4	0.027**	0.040
	(2.279)	(1.367)
Constant	0.450***	0.663***
	(3.559)	(4.507)
Observations	13,810	16,678
R-squared	0.266	0.153
Firm FE	YES	YES
Year FE	YES	YES

5.3. Regional Heterogeneity

The effectiveness of policy implementation often exhibits heterogeneity across different regions (Zhou and Qin, 2020). This phenomenon primarily stems from variations in economic development levels, market prosperity, and geographical conditions across regions in China. Specifically, the eastern region, with its economic foundation and geographical advantages, has established a relatively mature market economy system. This development enables the eastern region to more effectively mitigate supply chain risks through more flexible approaches and abundant resources. In contrast, the central and western regions, constrained by geographical location and other factors, still have room for improvement in their ability to resist supply chain risks. Given this, this paper divides China into eastern, central, and western regions based on the National Bureau of Statistics' classification criteria and hypothesizes that the carbon emissions trading pilot policy will have the strongest negative effect on supply chain risk levels in the eastern region.

The results reported in Table 7 confirm that the regression coefficient for the eastern region is significant at the 1% level, while those for the central and western regions are not strongly significant. This indicates significant regional differences in the impact of the carbon emissions trading pilot policy on corporate supply chain risk levels, with the policy having the most significant effect in the eastern region, validating the aforementioned hypothesis.

Table 7. Regional Heterogeneity Regression Results

	Eastern Region	Central Region	Western Region
Variable	*Bullwhip*	*Bullwhip*	*Bullwhip*
Treat_Post	-0.025***	-0.014	-0.008
	(-3.802)	(-0.850)	(-0.301)
Size	0.009***	0.008	0.006
	(2.651)	(1.123)	(0.910)
Lev	-0.017	0.092**	0.060
	(-0.835)	(2.008)	(1.444)
ROA	0.164***	0.317***	0.176*
	(3.850)	(3.572)	(1.655)
Growth	0.013*	0.014	0.009
	(1.888)	(1.236)	(0.991)
Board	-0.030	0.018	-0.004
	(-1.543)	(0.575)	(-0.128)
Indep	-0.075	-0.099	-0.001
	(-1.172)	(-0.821)	(-0.007)
Dual	-0.008	-0.023	-0.014
	(-1.378)	(-1.625)	(-0.889)
Top10	0.054***	0.089*	0.079*
	(2.631)	(1.897)	(1.714)
SOE	0.008	0.011	0.014
	(0.979)	(0.662)	(0.894)
Big4	0.026**	0.062**	0.047
	(1.985)	(2.072)	(1.345)
Constant	0.415***	0.298*	0.387**
	(4.353)	(1.747)	(2.326)
Observations	20,346	4,464	5,678
R-squared	0.208	0.210	0.175
Firm FE	YES	YES	YES
Year FE	YES	YES	YES

6. Mechanism Analysis

The aforementioned research indicates that the pilot policies for carbon emissions trading significantly reduces the level of supply chain risks. However, the specific pathways through which this policy affects supply chain risk levels remain unclear. Based on existing literature, this study infers that the carbon emissions trading policy influences supply chain risks through its impact on technological innovation ($Patent$), enterprise development quality ($GTFP$), and industrial structure (SEC). Therefore, this study references argument of Jiang Ting (2020) on causal inference and establishes the following models to examine its impact mechanism. The results are as follows:

$$Patent_{it}|GTFP_{it}|SEC_{it} = \beta_0 + \beta_1 Treat_{Post} + \beta_3 Controls_{it} + \sum Year + \sum Industry + \varepsilon_{it} \quad (3)$$

6.1. Green Patent Applications

This study adopts the method used by Yuan Zeming et al. (2024) and measures the degree of technological innovation in enterprises by summing the number of green invention patent applications and green utility patent applications, referred to as the total number of green patent applications ($Patent$). The regression results reveal a significantly positive effect of this policy on the number of green patent applications (significant at the 1% level). This indicates that the carbon emissions trading policy reduces supply chain operational risks by promoting low-carbon technological innovation in enterprises.

6.2. Green Total Factor Productivity

Zhang Mingming and Wang Kunmiao (2024) calculated the green total factor productivity (GTFP) by incorporating energy consumption and pollution emissions into the production function, which serves as a metric for assessing enterprise development quality. A higher value of this variable indicates better enterprise development quality. Following this method, our regression analysis shows a significantly positive effect of the policy on GTFP (significant at the 1% level). This suggests that the carbon emissions trading policy reduces supply chain risk levels by driving high-quality enterprise development.

6.3. Industrial Structure

Based on the research by Wang Huiying and Wang Ziyao (2021), this study used the ratio of coal consumption to total energy consumption to measure industrial structure, denoted as the energy consumption structure (SEC). A lower value of this variable indicates a greener industrial structure. The regression results, as shown in the table, demonstrate that the policy has a significantly negative impact on the energy consumption structure (with a regression coefficient of -0.443 and a t-value of -49.171, significant at the 1% level). This indicates that the carbon emissions trading policy enhances supply chain stability and reduces supply chain risks by encouraging enterprises to transition from traditional energy sources like coal to cleaner energy sources.

Table 8. Mechanism Analysis Regression Results

	(1)	(2)	(3)
Variable	*Patent*	*GTFP*	*SEC*
Treat_Post	3.063***	0.003***	-0.443***
	(3.342)	(12.556)	(-49.171)
Size	5.404***	0.001***	-0.006
	(6.456)	(6.223)	(-1.078)
Lev	-0.795	0.001	0.127***
	(-0.667)	(0.941)	(4.804)
ROA	0.830	-0.001	0.084
	(0.242)	(-0.559)	(1.499)
Growth	-0.623	0.013***	-0.001
	(-1.607)	(18.683)	(-0.172)
Board	-2.809	-0.000	0.075***
	(-1.397)	(-0.006)	(2.623)
Indep	14.699	-0.000	0.140
	(1.024)	(-0.117)	(1.602)
Dual	0.856	-0.000	-0.016**
	(1.041)	(-0.617)	(-1.980)
Top10	-2.014	-0.006***	-0.093***
	(-0.962)	(-7.498)	(-3.066)
SOE	-0.191	0.001***	0.025**
	(-0.253)	(4.255)	(2.109)
Big4	9.141*	0.001***	-0.086***
	(1.949)	(2.628)	(-4.386)
Constant	-114.544***	0.977***	0.720***
	(-5.776)	(317.947)	(5.393)
Observations	30,488	26,709	27,097
R-squared	0.099	0.139	0.408
Firm FE	YES	YES	YES
Year FE	YES	YES	YES

7. Conclusions and Policy Recommendations

Based on the data of China's A-share listed companies from 2008 to 2021, this paper studied the impact of the carbon emission trading pilot policies on corporate supply chain risk level using a quasi-natural experiment. The findings are as follows: (1) The carbon emission trading pilot policies significantly reduced the level of corporate supply chain risks, and the research results are robust. (2) The conclusions of the heterogeneity analysis show that the carbon emission trading pilot policies have a more significant inhibitory effect on the supply chain risks of state-owned enterprises, larger-scale enterprises, and enterprises located in eastern China. (3) The results of the mechanism analysis indicate that the carbon emission trading policies reduced supply chain risks by promoting enterprises' low-carbon technological innovation, driving high-quality development of enterprises, and encouraging enterprises to transform their industrial structure towards clean energy.

Based on the above conclusions, this paper puts forward the following policy recommendations: First, giving full play to the leading and driving role of state-owned enterprises, large-scale enterprises, and enterprises with good development momentum, and building a supply chain collaborative emission reduction mechanism with advantageous enterprises as the core. On the one hand, the government should issue relevant incentive policies, such as tax incentives and honorary awards, to encourage these enterprises to take the initiative to disclose supply chain management methods adapted to the carbon emission trading pilot policies. On the other hand, advantageous enterprises should actively fulfill their social responsibilities and establish assistance mechanisms to help other enterprises adjust their supply chain risk management. Second, improving the government support system, providing regional compensation mechanisms and special supporting for small and medium-sized enterprises, and reducing their emission reduction costs. In terms of regions, the government should reasonably determine compensation standards and methods according to factors such as industrial structure, economic development level, and carbon emission intensity in different regions. For small and medium-sized enterprises, the government can set up transformation support funds and provide low-carbon technology subsidies and structural transformation subsidies. Third, expanding the coverage of the carbon market, gradually promoting the carbon emission trading pilot policies from the current eight provinces and cities to the whole country, giving priority to covering high-emission manufacturing industries (such as steel and chemical industry), and gradually including small and medium-sized enterprises.

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