

How Does Green Finance Affects the Supply Chain Resilience of Heavily Polluting Enterprises ?

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Abstract. Considering the background of global supply chain restructuring and the Dual Carbon strategies, how green finance affects the real economy has drawn wide attention. Taking the Green Finance Reform and Innovation Pilot Zones (GFRIPZ) as a quasi-natural experiment, this study uses data of Chinese A-share listed heavily polluting manufacturing enterprises from 2011 to 2024 , and applies the staggered DID model to analyze the influence of green finance on enterprise supply chain resilience (SCR). This paper shows that GFRIPZ significantly inhibits the supply chain resilience of heavily polluting manufacturing firms. Its influencing mechanisms mainly include two paths: squeezing chain-stabilization funds and exacerbating financing constraints. Heterogeneity analysis shows that such negative policy effects are more prominent in non-state-owned, small-scale companies and those located in regions with weak environmental regulations. Overall, this study broadened the perspective on identifying green finance policies, as well as providing empirical evidence for coordinating green transformation with supply chain security and optimizing green finance policies.

Keywords: green finance reform and innovation pilot zones, the supply chain resilience, financing constraints, investment crowding-out

1. Introduction

At present, the global manufacturing industry chain and supply chain are undergoing accelerated reconstruction. More conflicts between countries and trade limits make supply chains easier to break down. With the in-depth implementation of Dual Carbon Goals, heavily polluting manufacturing enterprises are facing two main problems from stricter environmental rules and unstable supply chains. Green finance, as a key market-oriented tool for promoting low-carbon emission and optimizing resource allocation, is profoundly influencing the investment and financing structure of enterprises [1]. While, it will bring a series of complex impacts on the supply chain development of high-polluting corporations. Therefore, exploring the outcome caused by green finance policies such as the GFRIPZ is necessary.

SCR specifically means the comprehensive risk resistance and operational capacity of the supply chain. It can keep its basic functions and resume operations when facing external disturbances. On the macro level, natural disasters and public health emergencies [2] can weaken the supply chain resilience. From a micro perspective, firms are able to lift SCR through better ESG performance and

industrial digital transformation [3]. Technologies including artificial intelligence, the Internet of Things and Big Data can also strengthen the stability of industrial and supply chains .

With the green finance policy system being constantly improved, the green finance tools can provide long-term support for supply chain resilience by optimizing debt structure, promoting green innovation and enhancing investment efficiency [4]. Meanwhile, green finance may cause potential negative impacts, such as intensifying the enterprises' financial pressure, squeezing cash flow, weakening the risk buffering capacity of the supply chain and increasing operational risks [5]. In addition, policies like the GFRIPZ also have obvious heterogeneous effects. On the one hand, they can positively incentivize non-heavily polluting enterprises. On the other hand, they will also impose strong financing constraints and force emission reduction on heavily polluting enterprises [6]. To sum up, existing studies rarely focus on the connection between GFRIPZ and the resilience of enterprise supply chains. All of them lack comprehensive analysis on cost compliance effect and supply chain transmission mechanism [7].

Using panel data of China's A-share listed companies in the heavily polluting manufacturing industry from 2011 to 2024, this study takes GFRIPZ as a quasi-natural experiment to examine the impact on the SCR of heavy-pollution manufacturers. The paper makes two main contributions: (1) It identifies the restraining effects of green finance pilot policies based on SCR. And it also demonstrates the differentiated effects of policies comprehensively. (2) It clarifies the transmission logic of green finance policies and sets relevant research hypotheses from two influence paths, including tighter financing constraints and operating fund outflow caused by environmental protection investment.

2. Theoretical analysis and research hypotheses

The GFRIPZ guides social funds to flow into low-carbon and environmental protection fields through differentiated credit, environmental risk pricing and other means, and forces firms with high power consumption and heavy pollution discharge to make green transformation [8]. Heavily polluting enterprises have high self-discharge intensity and significant environmental compliance risks. With the policies being implemented, they will change the original business models of enterprises from multiple aspects, and therefore greatly influence the steady operation of firms' upstream and downstream supply chains. Unlike non-heavily polluting enterprises, heavily polluting enterprises face more direct effects from policy regulations. They are unable to mitigate the external shocks brought about by policies in the short term, and their supply chain collaboration efficiency and risk resistance capabilities decline rapidly in the short term [9]. Thus, I raise the research hypothesis below:

H1: The policies of the GFRIPZ have significantly reduced the SCR of high-polluting industrial entities.

Based on the theory of the crowding-out effect, due to the scarcity of capital elements, an increase in rigid investment by enterprises will directly squeeze the resource input in other business areas [10, 11], and green financial policies will exacerbate this phenomenon. Specifically, the green finance pilot policy forces heavily polluting corporations to put more money into green upgrades, thereby curbing the SCR of the enterprises from capital allocation. On the one hand, the policy forces heavily polluting firms to increase rigid environmental protection expenditures, directly diverting the core operating funds to ensure the stability of the supply chain, disrupting the normal turnover rhythm of the supply chain [12]. On the other hand, long-term investment in environmental protection will continue to occupy the financial resources of enterprises and reduce the allocation of resources for supply chain cooperation maintenance and risk buffering. The occupation of funds will

directly undermine the upstream and downstream collaborative relationship and intensify the operational risks of the supply chain [13, 14]. According to this, I propose the following hypothesis:

H2: The policy of the GFRIPZ reduces the SCR of heavily polluting enterprises by forcing enterprises to increase environmental protection investment and occupying production and supply chain operation resources.

Once the green finance pilot policy is in place, financial institutions follow environmental risk control and compliance rules. They tighten credit supply to high environmental risk firms and strictly limit credit quotas for heavily polluting enterprises. Less medium-long term and working capital loans are granted, which directly narrows their external financing channels. Accordingly, enterprises face a sharp drop in external funds needed for stable supply chain operation. Meanwhile, driven by the environmental risk pricing mechanism, financial institutions raise credit risk premiums for heavily polluting enterprises, further making the financing constraints [15]. Long-term market expectations are formed by policy trends. So their supply chains become less able to bounce back on their own, and they have a weaker capacity to handle risks. So, I put forward the following hypothesis:

H3: The pilot policies of green finance reduce the SCR of heavily polluting enterprises by intensifying their financing constraints.

3. Research design

3.1. Empirical model

3.1.1. Benchmark regression model

To examine the impact of GFRIPZ on SCR, this paper constructs a staggered DID model [16] for analysis. The specific settings are as follows

$$SCR_{ijt} = \alpha_0 + \alpha_1 GFRIPZ_{ijt} + \alpha_2 Controls_{it} + \delta_i + \mu_j + \theta_t + \varepsilon_{ijt} \quad (1)$$

Among them, the subscript i represents the enterprise, j represents the province, and t represents the time. SCR_{it} is the explained variable, representing the SCR. $GFRIPZ_{ijt}$ is the core explanatory variable, representing the green finance pilot policy. $Controls_{it}$ is a series of control variables. δ_i , μ_j and θ_t respectively represent individual fixed effect, industry fixed effect, and time fixed effect, and ε_{ijt} is the random error term. α_0 is the intercept term, and α_1 is the core regression coefficient of the research focus. If α_1 is clearly negative, so this means that GFRIPZ significantly reduces the SCR of heavily polluting manufacturing enterprises.

3.1.2. Mechanism Test Model

The mechanism testing model presented below is developed based on prior studies [17].

$$Mech_{ijt} = \beta_0 + \beta_1 GFRIPZ_{ijt} + \beta_2 Controls_{it} + \delta_i + \mu_j + \theta_t + \varepsilon_{ijt} \quad (2)$$

Among them, $Mech_{ijt}$ represents each mechanism variable determined in this paper. The settings of other variables and the meanings of parameters are consistent with the benchmark regression model (1). β_1 represents the core regression coefficient of concern during the mechanism verification process.

3.2. Variables

3.2.1. The explained variable: SCR

The explained variable is enterprise supply chain resilience (SCR). This paper refers to Zhang and Gu [18] to construct the supply chain resilience index which consists two dimensions: supply chain resistance and supply chain resilience. After standardizing each variable, we apply the entropy weight method approach to measure the comprehensive SCR index. We apply the entropy weight approach to measure the overall SCR index. Relevant indicator framework and variable explanations are illustrated in Table 1.

Table 1. Supply chain resilience measurement index system

First-level index	Second-level index	Connotation & Definition
Supply Chain Resistance (SCRs)	Financial Relationship	$\ln(\text{Accounts Receivable} / \text{Revenue})$
	Supply-Demand Stability	Number of non-new customers among the firm's top five customers / 5
Supply Chain Resilience (SCRI)	Product Flow	Inventory Turnover Ratio
	Performance Volatility	Economic Performance Sensitivity Index (EPSI)

3.2.2. The core explanatory variable: the Green Finance Pilot Zone Policy

The core explanatory variable is GFRIPZ. Specifically, A dummy variable ($treat_{ij}$) for the treatment group is set based on whether the firm's city has implemented the policy. Among them, enterprises in pilot cities get a 1, and those in non-pilot cities get a 0. Set the dummy variable ($post_{ijt}$) for the time. The year the policy starts and the years after that get a 1, and other years get a 0. GFRIPZ represents the dummy variable of the green finance pilot policy formed by the interaction and multiplication of $treat_{ij}$ and $post_{ijt}$.

3.2.3. Control variables

Referring to previous research findings [19, 20], this paper controls the following variables, including firm size ($size$), return on assets (roa), revenue growth rate ($growth$), equity concentration ($top1$), equity balance ($balance$), Tobin's Q ($tobin$), management shareholding ratio ($mshare$), executive compensation incentive (pay).

Table 2. Research variable settings

Variable Type	Variable Symbol	Variable Definition
The explained variable	SCR	calculated by the entropy weight method
The core explanatory variable	GFRIPZ	Policy dummy variable

Table 2. (continued)

Control variables	<i>size</i>	ln (Total Assets)
	<i>roa</i>	Net profit/Average balance of total assets
	<i>growth</i>	(current income – previous income) / previous income
	<i>top1</i>	The shareholding ratio of the largest shareholder
	<i>balance</i>	Largest share ratio / 2nd–5th top share ratio
	<i>tobin</i>	Market value/Total assets
	<i>mshare</i>	Number of shares held by senior executives/Total share capital
	<i>pay</i>	ln(Total Annual Salary of Management)

3.3. Sample and data

This paper uses the data of listed companies in Chinese A-share heavy-polluting manufacturing industry from 2011 to 2024 and conducts the following processing: (1) Eliminate enterprises with abnormal operations such as ST and *ST during the sample period. (2) Eliminate financial and real estate enterprises. (3) Eliminate enterprises with severely missing sample data. (4) To more accurately identify the influence of the green finance pilot policy shock on heavily polluting firms, only samples of enterprises that had gone public three years before the earliest policy shock began will be retained. (5) Apply a 1% upper and lower tail indentation to continuous data. The main data sources are CSMAR and CNRDS.

Table 3. Descriptive statistics

variables	N	Mean	SD	Min	P50	Max
SCR	6712	0.4528	0.1245	0.0836	0.4753	0.5972
GFRIPZ	6712	0.0341	0.1815	0.0000	0.0000	1.0000
<i>size</i>	6712	22.7565	1.3717	19.6951	22.5852	26.2203
<i>roa</i>	6712	0.0379	0.0624	-0.2309	0.0329	0.2244
<i>growth</i>	6712	0.1145	0.3352	-0.5691	0.0664	2.3431
<i>top1</i>	6712	0.3540	0.1506	0.0845	0.3360	0.7457
<i>balance</i>	6712	0.6158	0.5558	0.0231	0.4453	2.7509
<i>tobin</i>	6712	1.7114	1.0455	0.8431	1.3672	7.9971
<i>mshare</i>	6712	7.6091	15.2539	0.0000	0.0187	68.5586
<i>pay</i>	6712	15.3454	0.7419	12.9706	15.3135	17.3193

4. Empirical analysis

4.1. Baseline regression

Baseline regression results are displayed in Table 4. Column (1) only includes the explained variable SCR and the core explanatory variable GFRIPZ. The coefficient of the core explanatory variable is -0.0433 and significant at the 1% level. After all control variables are incorporated in Column (2), the coefficient changes to -0.0416 and remains statistically significant at the 1% level, which verifies the robustness of the core conclusion. Columns (3) and (4) further divide corporate supply chain resilience into risk resistance resilience and recovery resilience of supply chains. The coefficients of the core explanatory variable are also negative and significant at the 1% level. Overall, the green finance pilot policy exerts a significantly negative effect on enterprises' supply chain resilience, which verifies Hypothesis 1 of this study.

Table 4. Baseline regression results

	(1)	(2)	(3)	(4)
	SCR	SCR	SC_resis	SC_recov
GFRIPZ	-0.0433*** (-4.852)	-0.0416*** (-4.728)	-0.0989*** (-4.366)	-0.0066*** (-3.294)
<i>size</i>		0.0185*** (5.534)	0.0418*** (4.932)	0.0039*** (3.539)
<i>roa</i>		-0.0986*** (-3.880)	-0.1517** (-2.478)	-0.0604*** (-6.188)
<i>growth</i>		0.0079** (2.131)	-0.0319*** (-3.336)	0.0289*** (26.029)
<i>top1</i>		-0.1718*** (-6.534)	-0.3883*** (-5.831)	-0.0415*** (-5.018)
<i>balance</i>		-0.0306*** (-5.778)	-0.0711*** (-5.317)	-0.0060*** (-3.614)
<i>tobin</i>		0.0067*** (3.700)	0.0113** (2.525)	0.0039*** (5.794)
<i>mshare</i>		-0.0013*** (-5.527)	-0.0031*** (-5.602)	-0.0002* (-1.953)
<i>pay</i>		0.0081** (2.366)	0.0186** (2.179)	0.0019* (1.801)
_cons	0.4543*** (388.338)	-0.0110 (-0.134)	-0.3808* (-1.845)	0.2633*** (9.654)
Firm FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes

Table 4. (continued)

Year FE	Yes	Yes	Yes	Yes
N	6712	6712	6712	6712
r2_within	0.0034	0.0374	0.0322	0.1218

*p < 0.1, ** p < 0.05, *** p < 0.01

4.2. Identification validity test

4.2.1. The pre-trend test and heterogeneous treatment effect test

The Figure 1 shows that the assumption of the prior pre-trend test is not rejected, and the test is passed, so that means the GFRIPZ had a clear negative effect on the firms' supply chain resilience.

To conduct heterogeneous robust estimator test, this paper adopts the approach proposed by Sun and Abraham [21]. Figure 1 shows that after correcting for the heterogeneity estimation bias, the core conclusion remains robust, further strengthening the reliability of causal inference in the benchmark regression.

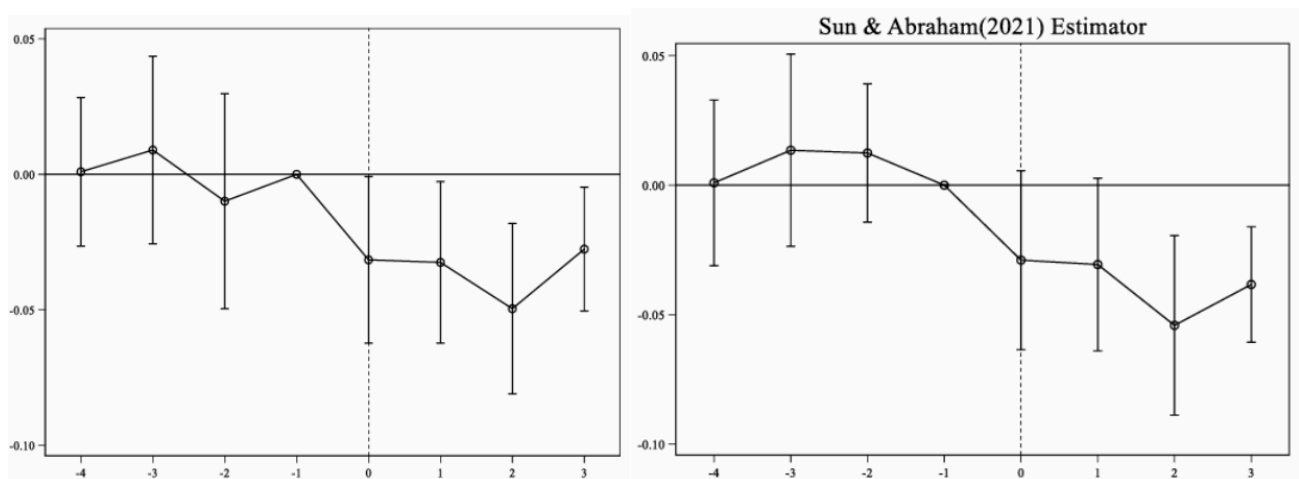


Figure 1. The pre-trend test and heterogeneous treatment effect test

4.2.2. Placebo Test

Referring to the approach of Chen et al. [22], this paper conducts In-time placebo tests, In-space placebo tests, Unrestricted mixed placebo tests, and Restricted mixed placebo tests respectively. Based on the four types of placebo tests, it shows that random factors and unobserved factors have a relatively small impact on the regression results, which verifies the benchmark regression results.

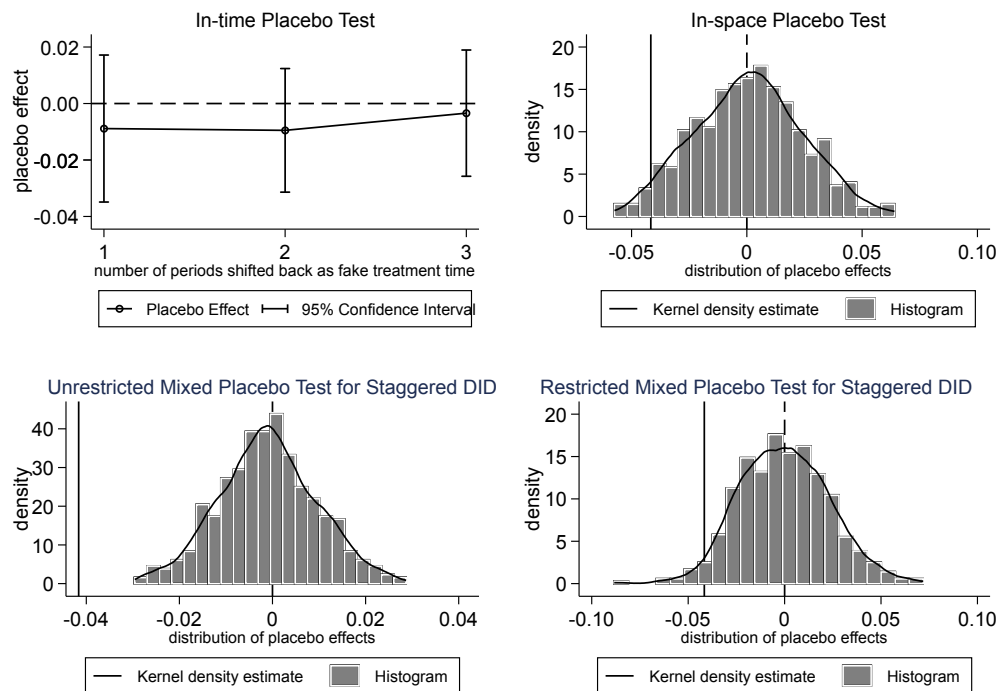


Figure 2. Placebo test

4.3. Robustness test

This study adopts the PSM-DID method for robustness tests. Its results are listed in Table 5 Column (1)-(2), which confirm the robustness of the benchmark regression conclusion.

Referring to Nguyen and Trinh [23] and replaces the measurement index of supply chain resilience. The results in Table 5 Column (3) show that the coefficient of core explanatory variable is -0.2541, which is significantly negative at the 1% level. The core conclusion has robustness at the index level.

Given the impact of major public health incidents in the sample years, this paper excludes the samples from 2020 to 2022 and performs regression again. As shown in Table 5 Column (4), the coefficient remains significantly negative at the 1% level, which confirms the robustness of the conclusion.

To control unobservable influences at industry and provincial levels, this paper further adds industry-year fixed effects and province-year fixed effects into the benchmark model. As shown in Table 5 Column (5)-(6), the coefficient of GFRIPZ is still significantly negative at the 1% level, which passes the robustness test.

Table 5. Robustness test

	PSM-DID		Replace the explained variable (3)	Eliminate special periods (4)	Add interactive fixed effects	
	1:1 matching (1)	kernel matching (2)			(5)	(6)
GFRIPZ	-0.0838** (-2.532)	-0.0191** (-2.192)	-0.2541*** (-3.233)	-0.0513*** (-5.122)	-0.0476*** (-5.261)	-0.0665*** (-5.370)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry×Year FE	No	No	No	Yes	No	Yes
Province×Year FE	No	No	No	No	Yes	No
N	325	6437	6738	5254	6712	6709
r2_within	0.0634	0.0239	0.0452	0.0402	0.0299	0.0412

4.4. Mechanism Test

4.4.1. Investment crowding-out mechanism

From the perspective that environmental protection investment forced by policies crowds out operational investment, this paper examines the mediating effect of the environmental investment channel in the process where GFRIPZ restrain SCR. Using enterprise environmental investment (EI) as the proxy variable for regression, the result of Table 6 Column (1) shows GFRIPZ positively affects EI, proving the policies push firms to increase rigid environmental investment and shift capital to environmental protection. Column (2) indicates EI negatively affects SCR. This demonstrates that the rising capital occupation for environmental protection continuously crowds out investment related to daily operation and supply chain maintenance, which ultimately markedly weakens enterprises' risk resistance capacity and stable operation capability of supply chains

4.4.2. Financing constraint mechanism

From the perspective that the policy tightens credit and raises external financing difficulties, this paper looks at how financing constraints work as a link between GFRIPZ and SCR. Referring to the research method of Hadlock and Pierce [24], the research adopts the SA index of financing constraints as the proxy variable. Table 6 Column (3) shows GFRIPZ positively affects financing constraints, meaning the policy reduces firms' financing accessibility and raises external financing pressure. Column (4) indicates financing constraints negatively affect SCR. When firms face more financing pressure, their capital turnover gets worse. Consequently, the comprehensive supply chain resilience of corporations undergoes a substantial decline.

Table 6. Mechanism test results

	Investment appropriation mechanism		Financing constraint mechanism	
	(1)	(2)	(3)	(4)
	EI	SCR	SA	SCR
GFRIPZ	3.8453*** (2.639)		0.0158*** (3.293)	
EI		-0.0005*** (-2.988)		
SA				-0.2216*** (-8.616)
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
N	4232	4232	6712	6712
r2_within	0.0163	0.0259	0.0940	0.0491

4.5. Heterogeneity Analysis

This paper conducts heterogeneity tests from three dimensions. We also take Fisher's Permutation Test to identify the differences in coefficients between groups. Table 7 presents the results.

For property rights attributes, the policy exerts no significant impact on state-owned enterprises (coef.=-0.0145), while it significantly weakens supply chain resilience of non-state-owned enterprises (coef.=-0.06<0.01), with significant inter-group differences. State-owned enterprises enjoy policy support and financing advantages that mitigate policy shocks, whereas non-state-owned enterprises suffer severe investment crowding-out and financing pressure. For firm size attributes, the policy significantly inhibits supply chain resilience of both large-sized firms (coef.=-0.026<0.1) and small-sized firms (coef.=-0.0540,<0.1). Compared with large firms, smaller firms with limited financing channels and weak risk resistance are more vulnerable to rising environmental costs that crowd out supply chain operational resources. For regional regulation attributes, green finance policy generates stronger negative effects in weakly regulated regions (coef.=-0.0641,<0.01) than in strongly regulated regions (coef.=-0.0257,<0.01). Firms in strictly regulated regions have mature green compliance systems to buffer policy impacts, while firms in weakly regulated regions face sudden compliance costs and capital outflow, resulting in a more severe decline in supply chain resilience.

Table 7. Heterogeneity analysis results

	nature of property rights		firm size		regulation intensity	
	(1) SOE	(2) Non-SOE	(3) Large	(4) Small	(5) High	(6) Low
GFRIPZ	-0.0145 (-1.356)	-0.0678*** (-4.693)	-0.0264** (-2.294)	-0.0540*** (-4.057)	-0.0257** (-2.365)	-0.0641*** (-4.296)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Differences	-0.053***		-0.028*		-0.038**	
N	3425	3287	3357	3355	3549	3163
r2_within	0.0111	0.0465	0.0145	0.0482	0.0490	0.0331

5. Conclusion

We want to examine the transmission mechanism through which green finance policies affect the supply chain resilience of heavily polluting firms. So we run a quasi-natural experiment with samples from 2011 to 2024 and applies the DID model. The policy is found to significantly weaken supply chain resilience by lowering capital allocation efficiency and operational stability via investment appropriation and financing constraints. Its adverse impact is stronger on non-state-owned, small enterprises and those in regions with lax environmental regulation.

This paper puts forward three suggestions: First, governments shall set proper policy intensity and transition periods to control short-term compliance costs. Targeted fiscal support and green technology assistance can supplement corporate funds and stabilize supply chain operations. Second, financial institutions need to optimize green credit mechanisms instead of adopting uniform loan limits. Expanding credit lines, extending loan terms and innovating financial products can ease financing pressure. Third, authorities shall implement differentiated regulation. The governments offer financing guarantees for non-state-owned enterprises, special funds for small firms and gradual compliance periods for enterprises in weakly regulated areas to lower supply chain risks.

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