Business Strategy and the Environment

WILEY | Business Strategy and the Environment

RESEARCH ARTICLE OPEN ACCESS

Supply Chain Configuration Adaptations of Highly-Polluting Firms in Response to Shocks From Environmental Pressures: Case for Centralization or Diversification?

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Received: 5 January 2025 | **Revised:** 26 August 2025 | **Accepted:** 4 September 2025

Funding: The authors received no specific funding for this work.

Keywords: environmental policy shocks | high-pollution firms | supply chain centralization

ABSTRACT

This study examines how environmental regulatory shocks affect the supply chain configuration of highly polluting firms, a relatively understudied area in the sustainable operations literature. Using a panel dataset of Chinese A-share listed firms from 2009 to 2022, we employ a Difference-in-Differences (DID) design to examine the causal impact of China's 2015 environmental policy reform on supply chain centralization. The results show that the supply chain structure of highly polluting firms shifted significantly towards centralization under the policy shock. Firms' green transformation and financial difficulty moderate this effect. Further heterogeneity analyses show that resource strength, geographical location, and dependence on external resources largely determine firms' adaptive responses. These findings underscore environmental regulations' strategic yet often overlooked impact on firms' supply chain decisions. They offer practical implications for policymakers seeking to align environmental objectives with industrial competitiveness and for managers responding to regulatory uncertainty through supply chain restructuring. Furthermore, this study enriches literature by establishing an empirical link between environmental regulation and supply chain design and uncovering the mediating mechanisms through which policy interventions influence firm strategy and sustainability outcomes.

1 | Introduction

In an uncertain economic and regulatory environment, supply chain configuration has become increasingly critical to firms' strategic positioning, survival, and resilience (Flynn et al. 2010). In supply chain management, firms must strategically select upstream suppliers and downstream customers and determine transaction intensity and scale, thereby shaping the degree of centralization in their supply chain relationships. Both centralized and diversified supply chain structures entail distinct trade-offs regarding operational efficiency, flexibility, and control. Compared with diversification, supply chain centralization helps to form stable and reliable upstream and downstream cooperative relationships; promotes cooperation in production, information sharing, and coinvestment among the companies upstream and downstream in the supply chain (Kinney and Wempe 2002); and enables enterprises to gain competitive advantages. However, as interdependence within supply chains deepens, cooperation often coexists with tension and asymmetry, particularly in vertically structured industry chains. Such tensions manifest in opportunistic behaviors such as withholding information or strategic manipulation by trading partners (Williamson 2007). In addition, firms with concentrated supply chains may be particularly vulnerable to pricing pressures from dominant upstream or downstream partners, which can erode their profitability (X. Zhang et al. 2020). Intensified global competition has prompted firms to reconsider supply chain partnerships (Wisner and Tan 2000; Lambert and Cooper 2000). However, the configuration of supply chains depends not only on the internal strategies of firms but also on the external policy environment. With the tightening of global environmental regulations, firms, especially those in highly polluting industries, face increasing pressure to reorganize their supply chains. Therefore, understanding how environmental policy shocks affect supply chain configuration choices is crucial for both firms and policymakers.

Academic views on supply chain configuration are divided into two main schools of thought, one of which emphasizes the benefits of supply chain centralization. For example, older management paradigms such as lean and total quality management argue that sourcing firms should establish close ties with a relatively concentrated group of suppliers in order to reduce costs and increase supplier commitment (Cousins 1999; Verma and Seth 2011). Furthermore, Upson and Wei (2024), Kim and Davis (2016), and Duan et al. (2020) find that higher supply chain concentration is associated with improved supply chain efficiency, greater operational visibility, and, in some cases, lower cost of debt. Moreover, several scholars argue that supply chain specialization and industrial agglomeration can contribute to economic growth, particularly in spatially heterogeneous economies such as China (Bai et al. 2004; Zeng et al. 2023). However, the findings of some scholars have challenged the above view, suggesting that a more positive impact could be realized through a broader and more complex configuration of supply chain diversification. Adobor and McMullen (2007) note that although sourcing trends favor consolidation, supplier diversification remains common among Fortune 500 firms and can be a source of competitive advantage when aligned with broader corporate strategy. For example, Ge et al. (2024) state that firms can increase sales and obtain higher product prices through diversification. In addition, Z. Hui (2023), Zou and Zhang (2023), and T. Liu and Gao (2022) in their studies have shown that supply chain centralization can adversely affect investment efficiency, profitability of a firm's main business, and corporate environmental responsibility performance, respectively. These dynamics often reflect an imbalance in bargaining power, whereby dominant supply chain actors may shift costs and risks onto weaker partners (Zhao 2019). Therefore, this ongoing debate suggests that optimal supply chain configurations remain context dependent.

Although supply chain configuration plays a critical role in enterprise operations, existing research has primarily focused on the outcomes of supply chain structures (Xu et al. 2023; Chen et al. 2023; W. He et al. 2024), while the antecedents or driving factors of supply chain configuration have received comparatively less attention. It has been found that supply chain configuration is influenced by factors such as green transformation, financial status, resource endowment, and geographical location of enterprises (X. Y. Liu et al. 2024; X. Li, Li, et al. 2024). A growing body of literature has examined the consequences of supply chain characteristics on various aspects of firm behavior. For example, Serpa and Krishnan (2018) studied the link between supply chain structure and productivity; Xue et al. (2018) explored how supply chain concentration affects firms' audit opinion avoidance; and Upson and Wei (2024) analyzed its impact on cost of capital. Other studies have addressed related themes such as supply chain relationship structure, digitization, and corporate financialization (Chen et al. 2023; Zou and Zhang 2023; H. He and Zuo 2023; H. He et al. 2023; H. Li, Wu, et al. 2024). Given the limited research on the factors influencing corporate supply chain configurations, this study addresses this gap by offering new perspectives on supply chain management strategies under environmental policy shocks.

Recognizing the strategic importance of supply chain configuration and the lack of sufficient attention it has received in previous studies, this research explores how environmental policy shocks affect firms' supply chain structures. In 2015, the most advanced and stringent environmental protection law in the history of China was officially implemented (B. Zhang and Cao 2015; B. Zhang et al. 2017). In the same year, China played a pivotal role in the formulation, ratification, entry into force, and implementation of the Paris Agreement, making a historically significant contribution. Taken together, 2015 represents a year of significant environmental regulatory shock in China. Moreover, because the revised environmental protection law primarily targeted heavily polluting enterprises and was formulated independently of firm-level characteristics, it can be regarded as an exogenous policy shock. This exogeneity helps address potential concerns of reverse causality and self-selection. Accordingly, many studies have employed this policy as a quasinatural experiment using the Difference-in-Differences (DID) approach to examine its effects on polluting firms (Fang et al. 2021; B. Lin and Zhang 2023; Ren and Liu 2024). Therefore, heavy polluters are also the focus of this paper. Thus, this study seeks to address two key questions: (1) whether such a stringent environmental policy shock has a significant impact on the supply chain configuration of heavily polluting firms and (2) which internal firm-level factors moderate this effect.

In order to address the above questions, we adopt an empirical research design. Specifically, we construct a panel dataset covering Chinese listed companies from 2009 to 2022 and use the DID model to identify causal relationships. Because this shock change in 2015 is exogenous to firms' supply chain choices, it reduces concerns about reverse causality. Given its wide-ranging impact on polluting firms, it is an ideal natural experiment for applying the DID model, as shown in previous studies (G. Wu, Sun, et al. 2024; Y. Liu et al. 2021; Fang et al. 2021). To validate our findings, we implement robustness checks, including the parallel trend test, placebo test, and propensity score matching–DID (PSM-DID) to address sample selection bias. We also introduce province fixed effects to control for regional heterogeneity. Furthermore, a

Difference-in-Difference-in-Differences (DDD) model is employed to examine potential moderating mechanisms. These methodological choices enable us to provide reliable insights into how environmental policies affect corporate supply chain decisions.

This study has three main contributions. First, to the best of our knowledge, our research is the first to empirically assess the impact of the environmental policy shocks that took effect in 2015 on highly polluting firms' supply chain configuration. There seems to be a relative abundance of empirical analyses of the implementation of China's environmental protection law, and scholars have found its impact on corporate green innovation (Y. Liu et al. 2021; Fang et al. 2021), corporate investment in financial assets (X. Liu and Liu 2022), corporate tax avoidance activities (Yu et al. 2021), and corporate environmental social responsibility (G. Wu, Sun, et al. 2024). However, literature exploring the impact of these policy shocks on firms' supply chain concentration is missing. Environmental policy shocks can significantly affect the behavior of firms (Sarkar 2008). In today's highly globalized economy, there is a need to clearly understand whether environmental policy shocks play an important role in firms' supply chain management. Our study aims to address this gap. In addition, by examining the impact of environmental policy shocks and highly polluting firms' supply chains in China, our empirical findings emphasize the influence of environmental policy shocks at the supply chain level in developing countries. The Chinese example can be a benchmark for other countries in implementing environmental policies and supply chain management.

Second, our diagnostic tests show that corporate green transformation and corporations' financial difficulty significantly mediate the relationship between environmental policy shocks and highly polluting firms' supply chain centralization. This suggests that it is extremely important to understand the role of firm management direction and financial situation on supply chain dynamics when developing and implementing supply chain strategies. Also, our findings provide important insights into why environmental policy shocks cause heavily polluting firms to gravitate towards more centralized supply chains while also providing valuable guidance for firms seeking to improve the sustainability of their supply chains.

Third, in the heterogeneity test, we find that resource-advantaged firms located in the eastern region and labor-intensive firms exhibit more pronounced effects in promoting supply chain concentration under the influence of environmental policy shocks. This finding provides valuable insights into the differential impact of environmental policy shocks on different highly polluting firms' supply chain centralization strategies. It suggests the need for targeted environmental policy measures tailored to these firms' unique capabilities and market position to enhance the effectiveness of their supply chain management and overall sustainable development efforts.

The sections below are organized as follows: Section 2 summarizes the policy background and theoretical hypothesis. Next, Section 3 describes the design of this research. Section 4 discusses the theoretical analysis and the empirical results obtained. In Section 5, we demonstrate further analysis of the article. Lastly, the study is concluded in Section 6.

2 | Policy Background and Hypothesis Development

2.1 | Policy Background

Over the past 30 years, China's environmental policy has evolved from weak regulatory enforcement to strict environmental governance and market-driven mechanisms. The "Environmental Protection Law of the People's Republic of China" was introduced in 1989, which made provisions in terms of environmental protection, supervision and management, pollution prevention and control, and legal responsibilities. It clarified the environmental governance obligations of various economic entities, but the reality of prioritizing economic development remained unchanged. Local government officials, in order to improve economic performance and gain political promotion, lowered local environmental standards. Enterprises, in pursuit of maximizing economic benefits, sought ways to evade environmental regulations, leading to difficulties in effectively improving the ecological environment. On January 1, 2015, the comprehensively revised "Environmental Protection Law of the People's Republic of China" was officially implemented. Its prominent feature is advocating the coordination of the development of the economy and the protection of the environment, strengthening the punishment for polluting enterprises, and the environmental supervision responsibilities of governments at all levels. It has been described as the "most stringent" environmental protection law of all time, bringing immense pressure on enterprises and governments for environmental governance (B. Zhang and Cao 2015; B. Zhang et al. 2017; B. Lin and Zhang 2023). In the same year, the 2015 Paris Climate Change Conference adopted the Paris Agreement, which set the long-term goal of limiting the increase in global average temperature to less than 2°C in the 21st century, in which China is also actively involved. In essence, with the Paris Agreement, the environmental governance paradigm has shifted to one in which national commitments, business implementation, and societal monitoring work in conjunction (J. Wang, Qiang, et al. 2024; Singh and Chudasama 2021).

Given the increasing regulatory pressure, firms in highly polluting industries must adapt their supply chain structures to balance compliance costs and operational efficiency. The following section explores how environmental policy shocks drive supply chain centralization, corporate green transformation's moderating roles, and financial difficulty.

2.2 | Hypothesis Development

2.2.1 | Environmental Regulation and Supply Chain Centralization

Environmental regulations greatly influence the strategic decisions of firms, especially in supply chain management. Firms, especially those in highly polluting industries, are under increasing pressure to comply with stricter environmental laws, which can lead to higher compliance costs, operational restructuring, and shifts in supply chain strategies (Y. Liu et al. 2021; Huang and Xie 2024).

First, the cost pressure of environmental compliance drives firms to optimize resource allocation. Stricter regulations require firms to invest in pollution control technologies and sustainable production methods, thus increasing the cost burden on heavily polluting firms (Cao et al. 2024). However, the Porter and Linde (1995), which posits that properly designed environmental regulations can enhance firms' competitiveness by stimulating innovation and improving efficiency, can be applied here to infer that well-designed regulations may ultimately benefit firms despite initial compliance costs. According to this view, firms may be able to exploit economies of scale by centralizing their supply chains and complying with regulatory standards in a cost-effective manner. To reduce these costs, firms prefer to centralize their supply chains by concentrating production with fewer, more reliable suppliers that meet environmental compliance standards, thereby achieving economies of scale and improving operational efficiency (Ponte 2022).

Second, supply chain centralization can enhance environmental monitoring and control. A more centralized supply chain structure allows firms to streamline oversight, enforce uniform environmental standards among suppliers, and improve traceability of emissions (W. Zhu and He 2017). This structure reduces wasted resources, improves compliance efficiency, and ultimately contributes to the achievement of corporate sustainability goals (Venugopal et al. 2025).

Finally, centralized supply chains facilitate environmental innovation and cooperation. Firms with more integrated supply chain networks are more capable of collaborating with key suppliers to develop green technologies, environmentally friendly materials, and sustainable logistics solutions, thereby enhancing their competitive advantage (Kinney and Wempe 2002; Pourhejazy et al. 2025).

Therefore, based on the above discussion, we propose the first hypothesis:

Hypothesis 1. *Strict environmental policy shocks can lead to a centralization of supply chain configurations for heavily polluting firms.*

2.2.2 | The Role of Corporate Green Transformation

On the positive side, green transformation is an important strategic response to environmental policy pressures and influences firms' supply chain choices. Although compliance with environmental regulations is mandatory, firms that adopt a proactive green transformation strategy can utilize environmental policies to improve efficiency, enhance market competitiveness, and gain policy incentives (Igwe et al. 2024).

First, efficiency gains from resource optimization–green transformation align with efficiency-driven supply chain centralization. Firms seeking to reduce their carbon footprint and increase resource efficiency may concentrate production and procurement within a network of smaller, well-managed suppliers (Z. Wang, Chu, et al. 2024). From a circular economy perspective, this shift enables companies to implement closed-loop supply chain practices such as material recycling, environmentally friendly packaging, and waste minimization, further reinforcing the benefits of supply chain centralization in sustainability management (Dey et al. 2022).

Second, market competitiveness and brand differentiation—besides regulatory compliance, green transformation is also a competitive strategy. As environmentally responsible entities, firms can attract eco-conscious consumers, investors, and business partners (Rao 2006; Nuryanto et al. 2024). Centralized supply chains enable firms to control better product quality, sustainability certification, and compliance monitoring, thereby strengthening their green brand positioning (Nuryanto et al. 2024).

Third, incentives and financial support—governments often provide fiscal incentives, green financing programs, and preferential policies to firms that demonstrate a strong environmental responsibility (B. Lin and Zhang 2023). These incentives make centralized supply chains more attractive, as tightly integrated supplier networks facilitate compliance reporting and eligibility for environmental subsidies (D. Wu, Ding, et al. 2024).

In conclusion, we propose the second hypothesis of this paper:

Hypothesis 2. *The green transformation of corporates enhances the effect of environmental policy shocks in driving supply chain configurations of heavily polluting firms towards centralized development.*

2.2.3 | The Role of Corporate Financial Difficulty

On the passive side, we believe that corporate financial difficulty could be another important factor. While green transformation is a proactive response, financial difficulties are a constraint that can also amplify firms' reliance on supply chain centralization. When faced with financial difficulties, heavily polluting firms prioritize cost-effectiveness, risk mitigation, and external support mechanisms, which reinforces the tendency towards supply chain centralization.

First, cost–benefit trade-offs within financial difficulties—companies under financial difficulties must allocate resources carefully, prioritizing cost reductions and operational efficiencies (Stranieri et al. 2017; Figueiredo et al. 2024). Supply chain centralization can minimize transaction costs, enhance price negotiations, reduce supply chain disruptions, and provide a more predictable cost structure (Lavastre et al. 2014).

Second, risk management and compliance assurance—firms facing financial difficulties are more vulnerable to penalties for environmental violations because they lack the resources to absorb regulatory fines or invest in alternative compliance strategies (Handfield et al. 2005). According to supply chain risk management theory, companies in financial distress prioritize risk reduction by increasing supply chain visibility and control. A centralized supply chain enhances a firm's ability to manage environmental risks, ensures stricter oversight, and reduces the risk of noncompliant suppliers (Jean 2024).

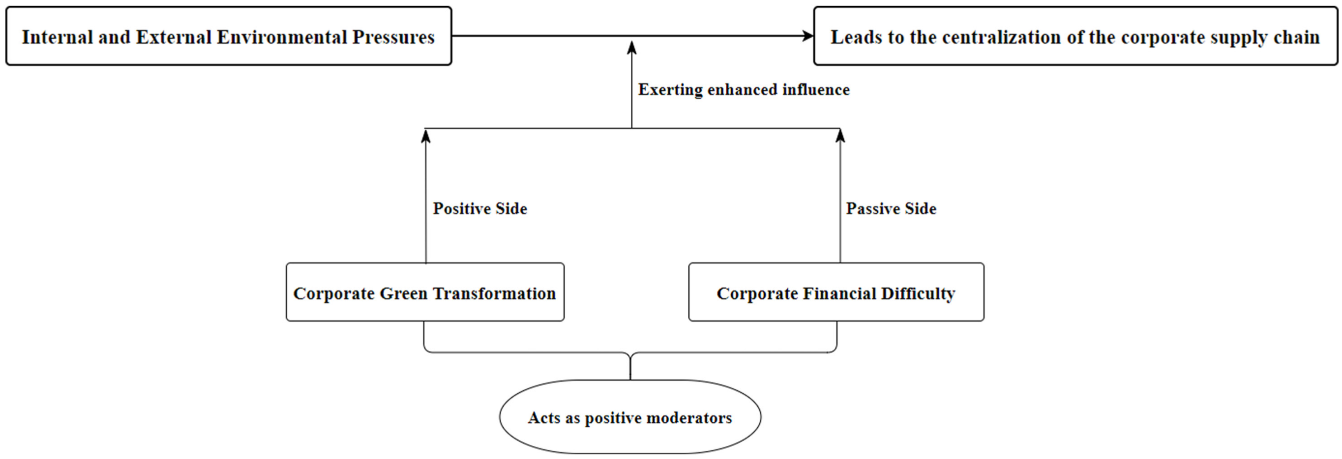

FIGURE 1 | The framework graph of influence mechanism.

Third, government support and policy adjustments—financially distressed firms often rely on government grants, tax credits, and financing programs to maintain operations. Many environmental policy incentives target firms that demonstrate good compliance and sustainability practices (Igwe et al. 2024). A centralized supply chain structure can help firms comply with policy expectations and make them more eligible for external financial assistance.

Therefore, we propose the third hypothesis of this paper:

Hypothesis 3. *The financial difficulty of corporates enhances the effect of environmental policy shocks in driving supply chain configurations of heavily polluting firms towards centralized development.*

In summary, Figure 1 shows the framework graph of the influence mechanism.

3 | Research Design

3.1 | Data Source and Sample Selection

We have selected A-listed companies listed on the Shanghai Stock Exchange and the Shenzhen Stock Exchange from 2009 to 2022 to conduct this study. To ensure the quality of the sample data, the sample data are conducted as follows: (1) exclude the sample of ST, *ST, and PT share companies; (2) exclude the sample of companies listed for less than 1 year, delisted, and suspended; (3) exclude companies in the financial industry from the sample due to their operational activity specificity; and (4) clustering at 1% and 99% percentiles of continuous variables to remove outlier interference. After the aforementioned processing of the data, 29,503 sample data were screened. The data were mainly obtained from the China Stock Market & Accounting Research (CSMAR) and Wind Information Co. (WIND) databases. A description of all the variables used in this paper is shown in Table 1.

In addition, a correlation matrix test is conducted to determine whether there is a covariance problem between the variables to ensure that there is no covariance problem between the variables. As shown in Table 2, it can be seen that there is no serious problem of multicollinearity between the explanatory variables and all the control variables.

3.2 | Variable Measurement

3.2.1 | Dependent Variable

Supply chain concentration refers to the degree of centralization of supply chain configurations, that is, whether an enterprise's sources of purchases and sales are concentrated in a small number of suppliers and customers that account for a relatively high proportion of its total purchases. In terms of upstream suppliers, an enterprise can be considered to have a high degree of supplier concentration if it purchases most of its goods mainly from a few top-ranked suppliers, such that the purchases from these suppliers account for a large proportion of the enterprise's total purchases. Conversely, an enterprise that purchases goods more evenly from multiple suppliers, such that purchases are spread out, can be considered to have a more diversified supplier allocation. Similarly, a firm's downstream customer selection can be measured using the degree of concentration of sales from major customers. Three supply chain concentration variables are constructed with reference to existing studies (K. W. Hui et al. 2012; Campello and Gao 2017; X. Zhang et al. 2020; Leung and Sun 2021; Ahsan et al. 2023): Upstream supplier concentration (*PT5r*) measures the proportion of purchases from a firm's top five suppliers in that year to its total purchases for the year; downstream customer concentration (*CT5r*) measures the proportion of sales from a firm's top five customers in that year to its total sales for the year; the overall supply chain concentration (*ST5r*) takes into account the average of the proportion of purchases from the top five suppliers and the proportion of sales from the top five customers of the enterprise for the year.

3.2.2 | Independent Variable

In this paper, the independent variables are the multiplication term (*treated*post*) of the heavy polluters (*treated*) and the

TABLE 1 | Summary statistics.

Variable type	Variable	Variable symbol	Obs	Mean	SD	Min	Median	Max
Dependent variables	Cross multipliers	*treated*post*	29,503	0.178	0.383	0.000	0.000	1.000
	Indicative variables	*post*	29,503	0.825	0.380	0.000	1.000	1.000
	Heavy polluters	*treated*	29,503	0.225	0.418	0.000	0.000	1.000
Independent variables	Supply chain concentration	*ST5r*	29,503	3.361	0.562	1.008	3.419	4.398
	Downstream customer concentration	*CT5r*	29,503	3.160	0.870	0.199	3.258	4.578
	Upstream supplier concentration	*PT5r*	29,503	3.371	0.612	1.664	3.405	4.531
Control variables	Net profit margin on total assets	*ROA*	29,503	0.039	0.066	−0.225	0.038	0.226
	Year of Establishment	*FirmAge*	29,503	2.943	0.323	1.792	2.996	3.526
	Cash flow ratio	*Cashflow*	29,503	0.048	0.068	−0.161	0.046	0.247
	Net profit growth rate	*NetProfitGrowth*	29,503	−0.383	3.655	−23.551	0.036	11.665
	Total assets growth rate	*AssetGrowth*	29,503	0.167	0.333	−0.285	0.089	2.214
	Whether or not there is a loss	*Loss*	29,503	0.125	0.331	0.000	0.000	1.000
	Tobin's *Q*	*TobinQ*	29,503	2.060	1.313	0.851	1.634	8.242
Mechanism variables	Corporate green transformation	*Greentransfer*	28,778	3.570	0.821	1.561	3.543	5.295
	Corporate financial difficulty	*Risk*	23,109	0.001	0.003	0.000	0.000	0.026

Abbreviations: Obs = observations; SD = standard deviation.

indicator variable (*post*). Among them, *treated* means the type of enterprise pollution. According to the Industry Classification Guidelines for Listed Companies revised by the China Securities Regulatory Commission in 2012, the Management List of Environmental Verification Industry Classification for Listed Companies established by the Ministry of Environmental Protection in 2008 (Environmental Protection Office Letter [2008] No. 373), and the Environmental Information Disclosure Guidelines for Listed Companies (Environmental Protection Office Letter [2010] No. 78), the sample is classified into two groups: heavy polluters and nonheavy polluters. If the company is a heavy polluter, *treated* is defined as 1; otherwise, *treated* is defined as 0. *post* is the environmental policy shocks indicator variable; *post* is defined as 0 before the policy shocks (before 2015) and 1 in the year of the policy shocks and after 2015; *treated*post* is the product term of *treated* and *post*, reflecting the net effect of the environmental policy shocks on the supply chain configuration of heavy polluters.

3.2.3 | Control Variables

Referring to Chu et al. (2019) and X. Liu and Liu (2022), considering the nature of the firm, its operating conditions, and external supervision, this paper selects Net profit margin on total assets (*ROA*), years of company establishment (*FirmAge*), cash flow ratio (*Cashflow*), net profit growth rate (*NetProfitGrowth*), total assets growth rate (*AssetGrowth*), whether or not there is a loss (*Loss*), and Tobin's *Q* (*TobinQ*) as control variables.

3.3 | Model Design

3.3.1 | Benchmark Regression Model

Because the effect of environmental shock falls mainly on heavy polluting industries, its enactment is independent of firms' supply chain configurations, eliminating the problems of reverse causality and self-selection, and therefore an external shock. The DID model, one of the main models for assessing policy shocks, has the advantages of being able to deal with endogeneity in a better way, with lower data requirements, and effortlessly capturing the short-term effects of policy changes. Therefore, to effectively assess the impact of environmental policy shocks on the supply chain configuration of heavy polluters, this paper refers to the study of B. Lin and Zhang (2023), considers the environmental policy shocks in 2015 to be an exogenous policy shock and applies the DID model to construct a benchmark regression model:

$$Y_{it} = \alpha_0 + \alpha_1 treated_i \times post_t + \alpha_2 X_{it} + \mu_i + \delta_t + \varepsilon_{it}, \quad (1)$$

TABLE 2 | Correlation coefficient matrix.

	ST5r	*treated*post*	*ROA*	*FirmAge*	*Cashflow*	*NetProfitGrowth*	*AssetGrowth*	*Loss*	*TobinQ*
ST5r	1.000								
*treated*post*	0.089***	1.000							
ROA	−0.040***	0.035***	1.000						
FirmAge	−0.037***	0.110***	−0.092***	1.000					
Cashflow	−0.067***	0.094***	0.426***	0.010*	1.000				
NetProfitGrowth	−0.025***	0.025***	0.417***	−0.022***	0.131***	1.000			
AssetGrowth	0.027***	−0.016***	0.311***	−0.119***	−0.014**	0.180***	1.000		
Loss	0.042***	−0.014**	−0.675***	0.073***	−0.210***	−0.449***	−0.209***	1.000	
TobinQ	0.122***	−0.071***	0.177***	−0.053***	0.104***	0.020***	0.018***	0.004	1.000
	CT5r	***treated*post***	***ROA***	***FirmAge***	***Cashflow***	***NetProfitGrowth***	***AssetGrowth***	***Loss***	***TobinQ***
CT5r	1.000								
*treated*post*	0.055***	1.000							
ROA	−0.061***	0.035***	1.000						
FirmAge	−0.049***	0.110***	−0.092***	1.000					
Cashflow	−0.099***	0.094***	0.426***	0.010*	1.000				
NetProfitGrowth	−0.027***	0.025***	0.417***	−0.022***	0.131***	1.000			
AssetGrowth	0.032***	−0.016***	0.311***	−0.119***	−0.014**	0.180***	1.000		
Loss	0.046***	−0.014**	−0.675***	0.073***	−0.210***	−0.449***	−0.209***	1.000	
TobinQ	0.085***	−0.071***	0.177***	−0.053***	0.104***	0.020***	0.018***	0.004	1.000
	PT5r	***treated*post***	***ROA***	***FirmAge***	***Cashflow***	***NetProfitGrowth***	***AssetGrowth***	***Loss***	***TobinQ***
PT5r	1.000								
*treated*post*	0.125***	1.000							
ROA	−0.000	0.035***	1.000						
FirmAge	−0.017***	0.110***	−0.092***	1.000					
Cashflow	−0.010*	0.094***	0.426***	0.010*	1.000				
NetProfitGrowth	−0.015**	0.025***	0.417***	−0.022***	0.131***	1.000			

(Continues)

TABLE 2 | (Continued)

	PT5r	*treated*post*	*ROA*	*FirmAge*	*Cashflow*	*NetProfitGrowth*	*AssetGrowth*	*Loss*	*TobinQ*
AssetGrowth	0.012**	−0.016***	0.311***	−0.119***	−0.014**	0.180***	1.000		
Loss	0.023***	−0.014**	−0.675***	0.073***	−0.210***	−0.449***	−0.209***	1.000	
TobinQ	0.127***	−0.071***	0.177***	−0.053***	0.104***	0.020***	0.018***	0.004	1.000

Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. All correlation coefficients are below 0.5 or above −0.5, indicating the absence of multicollinearity issues.

Where i represents the enterprise, t represents the year, and Y_{it} represents firm's supply chain configuration. $treated_i \times post_t$ is the dummy variable interaction term between *post* and *treated*, which captures the interaction between firms affected by the environmental policy and the postpolicy period. And its coefficient α_1 measures the net effect of environmental policy shocks on heavy polluters' supply chain configuration; X_{it} denotes the control variables. μ_i, δ_t, and ε_{it} denote firm fixed effect, year fixed effect, and random disturbance terms, respectively.

3.3.2 | Mechanism Test Model

Based on the model of DID, this paper also refers to the study of Rahman et al. (2024) to detect the influence mechanism of environmental policy shocks on the heavy polluters' supply chain configuration and adopts the DDD method. Compared with the conventional two-step method, the DDD model allows for further identification of the influence mechanism and understanding whether the effect of the independent variable on the dependent variable varies depending on the moderating variable. The model was constructed as follows:

$$\mathrm{Y}_{it} = \beta_0 + \beta_1 post_t \times treated_i \times M_{it} + \beta_2 post_t \times treated_i + \beta_3 M_{it} + \beta_4 X_{it} + \mu_i + \delta_t + \varepsilon_{it}, \quad (2)$$

where M_{it} denotes the moderating variable, based on the previous theoretical analysis, this paper selects two moderating variables, corporate green transformation and corporate financial difficulty to test the influence mechanism. The interaction term $treated_i \times post_t \times M_{it}$ allows us to test whether the policy effect varies across firms with different levels of green transformation or financial difficulty. If β_2 is statistically significant, it indicates that the moderating variable plays a crucial role in shaping firms' adaptive strategies. The remaining variables retain the same interpretations as in model (1).

4 | Measurement Results and Empirical Analysis

4.1 | Benchmark Regression Result

Results of the benchmark regression are provided in Table 3, in which Columns (1)–(3) examine the effect of environmental policy shocks on upstream supplier concentration (*PT5r*), downstream customer concentration (*CT5r*), and supply chain concentration (*ST5r*), respectively, controlling for firm characteristics and year and individual fixed effects. The results show that the coefficient of *treated*post* in Columns (1)–(3) are positively correlated at the 1% level of significance, which means that the supply chain configuration of heavily polluting firms is towards centralization in the face of strong environmental pressures. This result is consistent with Hypothesis 1.

Our findings are consistent with previous research that regulatory pressure causes firms to reorganize their supply chains to improve efficiency and compliance (Q. Zhu et al. 2011). For example, Hsu et al. (2013) find that under stringent environmental regulations, firms reduce the number of suppliers and

TABLE 3 | Difference-in-Differences for the corporate supply chain concentration.

VarName	(1) *ST5r*	(2) *CT5r*	(3) *PT5r*
*treated*post*	0.0437***	0.0580***	0.0503***
	(3.9938)	(3.7189)	(3.7201)
ROA	0.1828***	0.1430*	0.1958***
	(3.2381)	(1.7883)	(2.8623)
FirmAge	−0.0846**	−0.1097*	−0.0540
	(−2.0752)	(−1.8688)	(−1.0704)
Cashflow	−0.0839**	−0.2319***	−0.0488
	(−2.3886)	(−4.2721)	(−1.1311)
NetProfitGrowth	0.0003	0.0014*	−0.0003
	(0.5539)	(1.6915)	(−0.4090)
AssetGrowth	0.0060	0.0213**	0.0007
	(0.8396)	(2.1016)	(0.0851)
Loss	0.0112	0.0101	0.0154
	(1.3065)	(0.8093)	(1.4757)
TobinQ	0.0127***	0.0184***	0.0091***
	(5.5393)	(5.5437)	(3.1393)
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
_cons	3.5709***	3.4361***	3.4947***
	(29.7538)	(19.8819)	(23.5195)
N	29,503	29,503	29,503
R^2	0.7790	0.8126	0.7089

Note: (1) Robust standard errors are reported in parentheses. (2) ***, **, and * denote 1%, 5%, and 10% significance levels. (3) Firm FE and Year FE denote firm-level and year fixed effects, respectively.

enhance the environmental compliance assessment of suppliers. Similarly, G. C. Wu et al. (2012) argue that firms in Taiwan's textile industry tend to establish long-term cooperation with fewer, but more reliable, suppliers to ensure compliance due to environmental regulations. Our findings further support this view as we provide empirical evidence that highly polluting firms respond to environmental shocks by increasing supply chain concentration.

However, our findings also contrast with those that suggest that regulatory uncertainty may encourage diversification as a risk mitigation strategy. For example, Prater et al. (2001) and Villena et al. (2021) find that firms operating in highly uncertain regulatory environments tend to diversify their supply chains to avoid compliance risks. By contrast, our findings suggest that in the context of such a large environmental shock in China in 2015, firms responded mainly through centralization, possibly due to the predictability of regulatory enforcement and financial incentives favoring compliance-oriented supply chain strategies. This suggests that the regulatory environment and enforcement mechanisms play a crucial role in shaping firms' supply chain responses.

4.2 | Robustness Test

This paper conducts additional tests from several perspectives to verify the robustness of the benchmark regression results. Specifically, they include a parallel trend test, a placebo test, propensity score matching, adding province fixed effects, excluding supply chain policy effects, shortening the sample interval, controlling for financial transparency and corporate governance factors, and considering policy lag effects. The above analyses help to enhance the credibility and robustness of the study findings.

4.2.1 | Parallel Trend Test

In the DID model, the parallel trend test is the fundamental premise, which requires that the treatment group and the control group have the same change tendency prior to implementing the policy. This paper adopts the event study method to make the parallel trend test and select the interval between −5 and 5 to construct model (3). It also replaces the outlier values for the year of policy implementation in the treatment and comparison groups that were not between −5 and 5 with the default value of −5 or 5, to avoid disturbing the analysis of the results.

$$Y_{it} = \alpha + \sum_{k=-5}^{k=5} \beta_k treated_i \times post_k + \gamma X_{it} + \mu_i + \delta_t + \varepsilon_{it}, \quad (3)$$

where k denotes the year number before and after the environmental policy shocks, and if k is minus, it represents the kth year before policy implementation. The interaction term's coefficient, β_k, is used to measure how the treatment and control groups differ at the k_{th} period, and the other variables used are identical to model (1).

Figures 2–4 shows the parallel trend test results. The coefficient estimates in the 5 years before environmental policies shock across the 0 line, indicating that the trend in supply chain concentration change of heavy polluters and nonheavy polluters before policy shocks is not significantly different, which meets the parallel trend test. After the environmental policy shocks, the estimated coefficient of environmental policy shocks significantly deviates from the 0 lines, indicating that the policy shocks provide a positive influence on the supply chain concentration level of heavily polluting enterprises. The parallel trend test is passed.

4.2.2 | Placebo Test

Figures 5–7 present the findings of the unrestricted mixed placebo test, which uses both pseudotreated individuals and

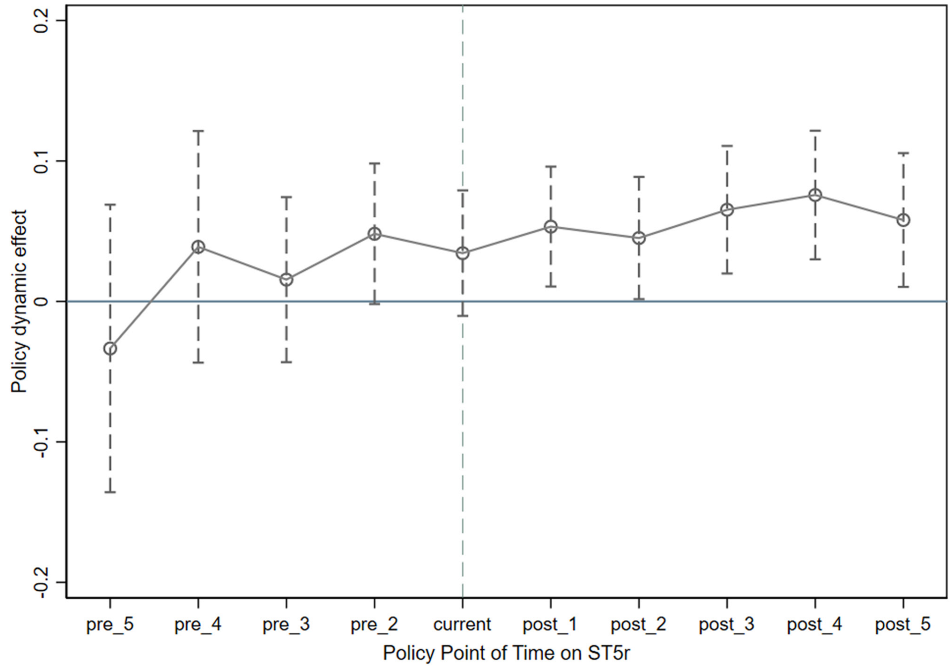

FIGURE 2 | The results of parallel trend test on *ST5r*. *Note:* To avoid multicollinearity, *pre_1* is dropped as the base period ($k \neq -1$).

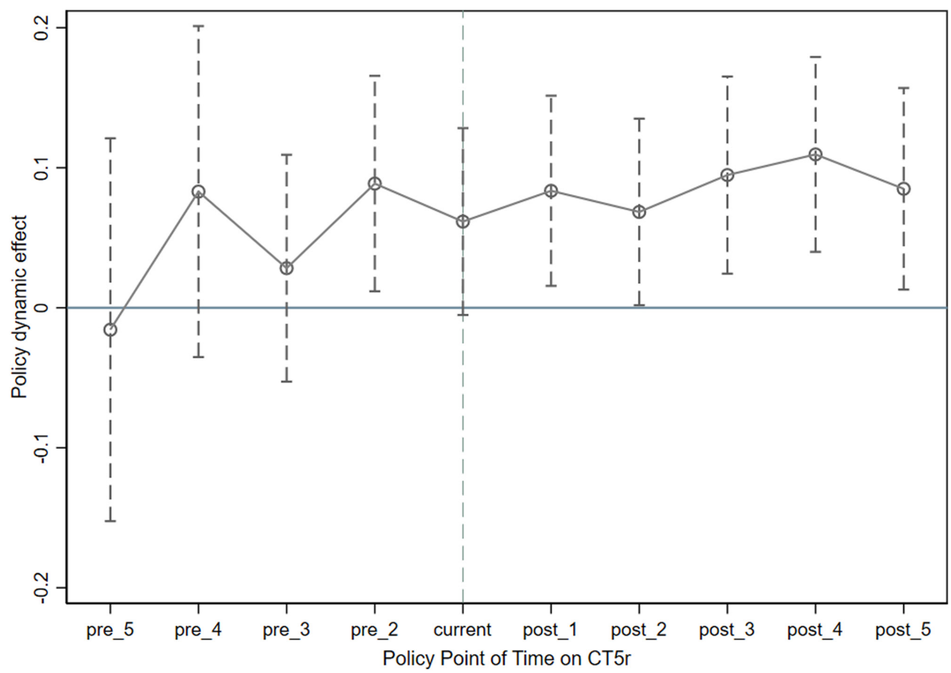

FIGURE 3 | The results of parallel trend test on *CT5r*. *Note:* To avoid multicollinearity, *pre_1* is dropped as the base period ($k \neq -1$).

pseudotreated times. Specifically, based on the earliest and latest times in the sample, pseudotreated times for each individual are randomly drawn from a uniform distribution within this range, and two-stage least squares estimation (TWFE) estimation is conducted with 500 repetitions to obtain the distribution of the placebo effect. The results show that the treatment effect estimate (indicated by the vertical solid line in the figure) is located at the far right of the placebo effect distribution and is therefore an unusually extreme value for robustness. Therefore, the results pass the placebo test.

4.2.3 | PSM-DID and Adding Province Fixed Effect

Although the DID method separates the average treatment effect of the policy shocks, the observational study data may still suffer from the problem of selection bias. To address this issue, this paper conducts further robustness tests based on the PSM-DID model. Table 4 Panel A reports the results of the PSM-DID regression. The results show that the coefficient of *treated***post* is still significantly positive and does not differ much from the baseline regression results, which to some extent suggests that

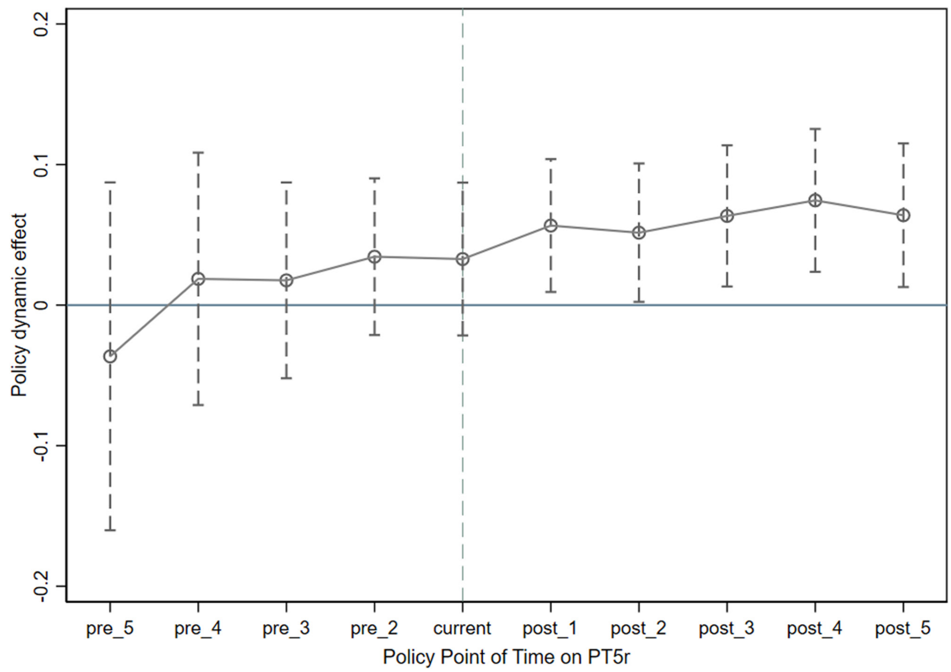

FIGURE 4 | The results of parallel trend test on *PT5*. *Note:* To avoid multicollinearity, *pre_1* is dropped as the base period ($k \neq -1$).

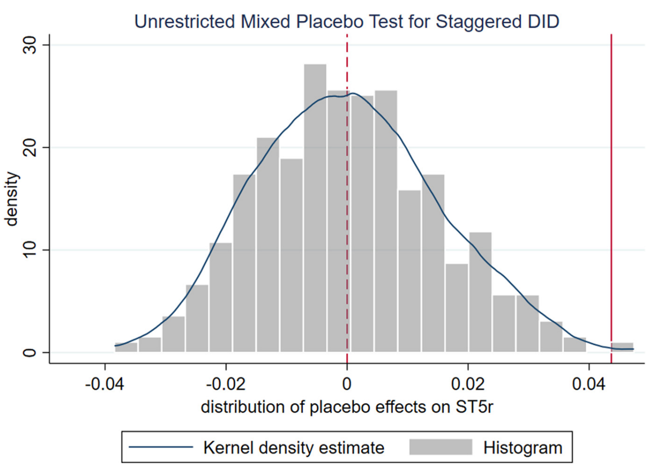

FIGURE 5 | Mixed placebo test graph on *ST5r*.

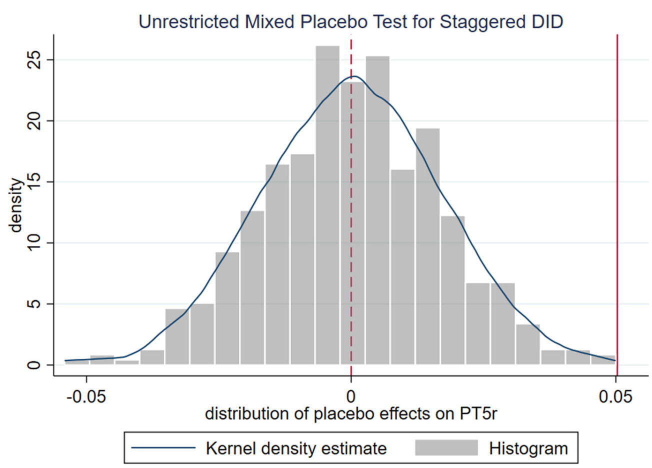

FIGURE 7 | Mixed placebo test graph on *PT5r*.

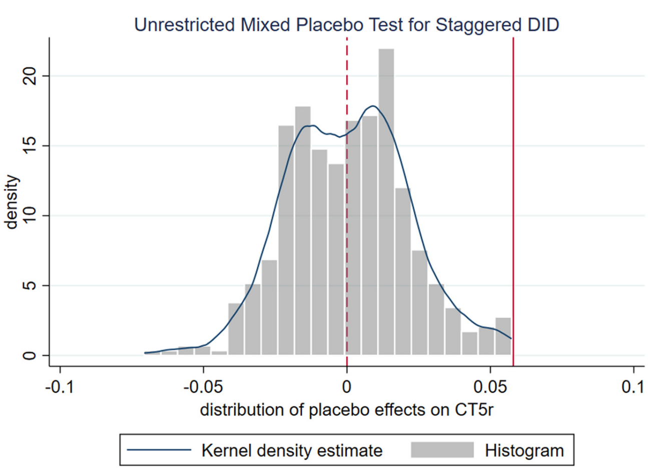

FIGURE 6 | Mixed placebo test graph on *CT5r*.

the upward effect of environmental policy shocks on firms' supply chain centralization is robust. In addition, we also report the results of adding province fixed effect in Table 4 Panel B. From the coefficient result, we can see that the result remains significant, further increasing the reliability of the paper's findings.

4.2.4 | Excluding Supply Chain Policy Impact

The Ministry of Commerce of China and eight other departments launched a pilot project on supply chain innovation and application in 2018, proposing to promote the formation of an industry supply chain system that is innovation led, synergistic, industry financing integrated, supply-and-demand matching, high quality and high efficiency, green and low carbon, and global in scope. Therefore, the trend of heavily polluting enterprise supply chain centralization may be influenced by the above-mentioned

TABLE 4 | Robustness test—PSM-DID and adding province fixed effect.

VarName	(1) *ST5r*	(2) *CT5r*	(3) *PT5r*
Panel A: PSM-DID			
*treated*post*	0.0437***	0.0579***	0.0504***
	(3.9915)	(3.7119)	(3.7269)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Province FE	No	No	No
_cons	3.5709***	3.4360***	3.4949***
	(29.7512)	(19.8798)	(23.5187)
N	29,497	29,497	29,497
R^2	0.7789	0.8125	0.7089
Panel B: Adding province fixed effect			
*treated*post*	0.0407***	0.0547***	0.0482***
	(3.8007)	(3.5902)	(3.5876)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Province FE	Yes	Yes	Yes
_cons	3.5339***	3.3746***	3.4659***
	(29.8373)	(19.8009)	(23.4794)
N	29,503	29,503	29,503
R^2	0.7801	0.8141	0.7096

Note: See notes in Table 3.

TABLE 5 | Robustness test—Excluding the impact of supply chain innovation and application pilot policies.

VarName	(1) *ST5r*	(2) *CT5r*	(3) *PT5r*
Panel A: Exclusion of supply chain pilot enterprises			
*treated*post*	0.0434***	0.0550***	0.0518***
	(3.9353)	(3.4995)	(3.8059)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
_cons	3.5776***	3.4508***	3.4734***
	(29.7067)	(19.7793)	(23.5395)
N	29,084	29,084	29,084
R^2	0.7765	0.8106	0.7074
Panel B: Exclusion of supply chain pilot cities			
*treated*post*	0.0303**	0.0442**	0.0375**
	(2.4127)	(2.4899)	(2.4039)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
_cons	3.7814***	3.7818***	3.7532***
	(24.6975)	(17.2556)	(19.9950)
N	18,795	18,795	18,795
R^2	0.7632	0.8096	0.6955

Note: See notes in Table 3.

national supply chain policy. It is necessary to exclude the possible impact of the national supply chain innovation and application pilot policy on heavy polluters supply chain configuration by excluding the pilot enterprises and pilot cities in the pilot list that overlap with the sample from the samples of the pilot year and beyond, and re-examining them. After excluding the samples of supply chain pilot enterprises and pilot cities, respectively, the regression results are shown in Table 5, and it is found that the coefficient of *treated*post* is still significantly positive. This suggests that after removing the impact of the national supply chain innovation and application pilot policy, the environmental shocks still increase the upstream, downstream, and overall concentration of highly polluting firms' supply chains and promote the centralization of supply chain configurations, which once again corroborates the basic conclusions of this paper.

4.2.5 | Shortened the Sample Interval

To further verify the robustness of the impact of policy shocks on firms' supply chain configuration, we shorten the sample time interval to 2012 to 2018, that is, we use 2015 as the year of the shock, and the data of the 3 years before and after as the research sample. This move aims to more accurately capture the short-term direct effects before and after the introduction of the policy and exclude the interference of long-term trends and other external factors.

The empirical results are presented in Table 6. After shortening the sample interval, the key variables in the model (*ST5r*, *CT5r*, and *PT5r*) are still statistically significant, and the direction of the coefficients is consistent with the estimation results under the original sample interval (2009–2022). This suggests that the effect of policy shocks on the supply chain configuration of highly polluting firms remains significant over the short-term sample interval.

4.2.6 | The Influence of Financial Transparency and Corporate Governance Factors

To further improve the robustness of our findings and to consider potential systematic effects related to financial transparency and corporate governance, we introduce two additional control variables: *Mfee* (management expenses divided by operating revenues) and *AuditFee* (audit fees). *Mfee* reflects the extent

TABLE 6 | Robustness test—Shorten the sample interval.

VarName	(1) ST5r	(2) CT5r	(3) PT5r
*treated*post*	0.0231**	0.0377**	0.0269*
	(1.9828)	(2.3255)	(1.7936)
ROA	−0.0459	−0.0936	−0.0874
	(−0.4992)	(−0.7083)	(−0.7632)
FirmAge	−0.0851	−0.0384	−0.0732
	(−1.1765)	(−0.3885)	(−0.7879)
Cashflow	−0.1316**	−0.3099***	−0.0589
	(−2.4434)	(−3.8809)	(−0.9093)
NetProfitGrowth	0.0004	0.0011	0.0005
	(0.4352)	(0.8807)	(0.4641)
AssetGrowth	−0.0095	0.0082	−0.0144
	(−1.0105)	(0.6272)	(−1.3109)
Loss	−0.0146	−0.0286	0.0004
	(−1.0631)	(−1.4991)	(0.0231)
TobinQ	0.0122***	0.0228***	0.0064
	(3.4862)	(4.3525)	(1.4454)
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
_cons	3.5582***	3.1797***	3.5667***
	(17.1786)	(11.2472)	(13.3870)
N	13,673	13,673	13,673
R^2	0.8006	0.8315	0.7333

Note: See notes in Table 3.

of management expenses relative to operations and is often associated with agency costs and governance efficiency (Feng et al. 2023). *AuditFee* is commonly used as a proxy for financial transparency and audit quality, as higher audit fees may reflect more rigorous audits and greater disclosure (Hay et al. 2006).

The empirical results are presented in Table 7. After incorporating these controls, our results are not affected by differences in financial management practices or governance structures between firms, which remain statistically significant, consistent with previous estimates. The coefficients on the policy shocks remain positive and significant, suggesting that environmental policies continue to drive supply chain concentration among heavily polluting firms even after accounting for these governance-related factors.

TABLE 7 | Robustness test—The influence of financial transparency and corporate governance factors.

VarName	(1) ST5r	(2) CT5r	(3) PT5r
*treated*post*	0.0252**	0.0398**	0.0318**
	(2.3077)	(2.4953)	(2.3644)
ROA	0.1694***	0.1739**	0.1673**
	(2.9714)	(2.1319)	(2.4142)
FirmAge	0.0106	−0.0132	0.0402
	(0.2583)	(−0.2192)	(0.7953)
Cashflow	−0.0591*	−0.2031***	−0.0203
	(−1.6913)	(−3.7092)	(−0.4717)
NetProfitGrowth	0.0005	0.0015*	−0.0001
	(0.8198)	(1.7784)	(−0.1898)
AssetGrowth	0.0112	0.0261***	0.0065
	(1.5747)	(2.5775)	(0.7818)
Loss	0.0154*	0.0103	0.0212**
	(1.8110)	(0.8226)	(2.0464)
TobinQ	0.0069***	0.0119***	0.0036
	(3.0612)	(3.6182)	(1.2381)
AuditFee	−0.1632***	−0.1435***	−0.1783***
	(−16.1849)	(−9.3817)	(−15.2162)
Mfee	0.0412	0.2797***	−0.0266
	(0.6882)	(2.8868)	(−0.3678)
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
_cons	5.5432***	5.1136***	5.6826***
	(32.0677)	(20.3351)	(27.0872)
N	29,191	29,191	29,191
R^2	0.7835	0.8135	0.7151

Note: See notes in Table 3.

4.2.7 | Policy Lag Effect Test

The effects of exogenous policy shocks tend to be time lagged, and to further clarify the lagged effects of environmental policy shocks, we lagged the explained variables in the study of this paper (*ST5r*, *CT5r*, and *PT5r*) by one, three, and five periods, respectively, to observe their lagged effects. The findings are given in Table 8. The results in Table 8 show that the policy effect continues to diminish as time recedes until it disappears completely at Lag 5. This indicates that environmental policy shocks have lagged effects and show a gradual weakening trend. The signs of the coefficients are also consistent with our baseline regressions, again demonstrating the robustness of our results.

4.3 | Mechanism Test

According to model (2) in the above model design, we test how corporate green transformation and corporate financial

TABLE 8 | Policy lag effect test.

	Lagged one-period effect			Lagged three-period effect			Lagged five-period effect		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
VarName	***ST5r***	***CT5r***	***PT5r***	***ST5r***	***CT5r***	***PT5r***	***ST5r***	***CT5r***	***PT5r***
*treated*post*	0.0474***	0.0595***	0.0528***	0.0557**	0.0692**	0.0480*	0.0481	0.0240	0.0417
	(3.2954)	(2.9242)	(3.0302)	(2.4728)	(2.0734)	(1.7613)	(1.4261)	(0.5237)	(0.9743)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
_cons	3.6629***	3.4666***	3.5622***	3.5714***	2.9167***	3.5990***	4.3434***	2.7893***	4.9768***
	(24.0336)	(15.9802)	(18.7067)	(15.0983)	(8.6083)	(12.5535)	(11.3442)	(5.0187)	(10.1055)
N	23,498	23,498	23,498	16,889	16,889	16,889	10,770	10,770	10,770
R^2	0.7923	0.8287	0.7229	0.7981	0.8297	0.7309	0.7984	0.8283	0.7289

Note: See notes in Table 3.

difficulty moderate the intrinsic relationship between environmental policy shocks and heavily polluting firms' supply chain concentration, respectively. The following tests and analyses are conducted.

4.3.1 | Corporate Green Transformation

According to Loughran and McDonald (2011), the textual information in annual reports is an effective way to assess the greening transformation of businesses. In comparison with the method of content analysis, the method of text analysis uses computational natural language processing technology, which can precisely identify information in unstructured text with large sampling sizes, thus lowering the error rate and enhancing the consistency of judgments. Relevant data are taken from the annual reports of listed firms, the social responsibility reports of listed firms, and information on the websites of listed firms. Choosing annual reports of listed enterprises as the research object has two major advantages: Firstly, greening transformation as key strategic information is usually disclosed in public documents with a wide audience, such as annual reports, which is compatible with the synthesizing and indicative nature of annual reports; secondly, listed companies' annual reports are compulsory disclosures and follow rigorous formats and specifications, which improves the effectiveness of keyword matching. According to the five key factors proposed by Hart (1995), which are based on the green capabilities of products and production processes, employee training, green organizational capabilities, environmental management system, and environmental strategic planning, enterprises can produce green products and reduce pollution emissions through green technological innovations, thus achieving improved corporate performance and sustainable development. Based on the Environmental Protection Law, the Five-Year Plan, the White Paper on Green Manufacturing Standardization, the Technical Guidelines for the Evaluation of Corporate Environmental Behaviour, and other policy documents, as well as relevant studies, 113 keywords for the greening transformation of enterprises (see Table A1) were selected, combining publicity initiatives, strategic concepts, technological innovation, sewage treatment, and monitoring and management. We also count the number of times these keywords appear in the reports of listed companies in order to portray the greening transformation of enterprises in natural logarithm.

Columns (1)–(3) of Table 9 provide the regression results. The results demonstrate that the coefficients of the interaction term *treated*post*Greentransfer* are positive and significant at least at the 10% level for overall supply chain centralization (*ST5r*) and upstream suppliers (*PT5r*), suggesting that highly polluting firms' green transformation has led to an increase in the centralization effect of environmental policy shocks promoting its supply chain. This result is consistent with Hypothesis 2.

However, the downstream customer supplier (*CT5r*) is not significant, and we analyze two possible reasons for this: (1) Supply chain management strategy: When promoting green transformation, highly polluting companies may give preference to suppliers that can meet their environmental standards, which may lead to a more concentrated selection of suppliers to ensure green compliance across the supply chain (Jha et al. 2024). The downstream customer side, on the other hand, involves a wider range of markets and consumer groups, so changes in concentration will not be as pronounced. (2) Market responsiveness: Upstream suppliers are usually more responsive to changes in corporate policies because they have a direct relationship with the corporate. The downstream customer side, on the other hand, involves consumer behavior and market dynamics, and changes in these factors are usually slower, so changes in concentration will also not be immediately apparent (Pil and Holweg 2006; Foerstl et al. 2015). However, taken as a whole (*ST5r*), environmental policy shocks do have a positive impact on the supply chain concentration of heavy polluters. This is consistent with the findings of Jha et al. (2024) that firms operating under stringent environmental regulations often integrate their supply chains as a

TABLE 9 | Possible mechanisms.

	Corporate green transformation			Corporate financial difficulty		
	(1)	(2)	(3)	(4)	(5)	(6)
VarName	*ST5r*	*CT5r*	*PT5r*	*ST5r*	*CT5r*	*PT5r*
*treated*post*Greentransfer*	0.0135**	0.0103	0.0125*			
	(2.3692)	(1.3123)	(1.7253)			
*treated*post*	−0.0077	0.0195	0.0024	0.0318***	0.0450***	0.0383***
	(−0.3318)	(0.6095)	(0.0824)	(2.7407)	(2.7453)	(2.6718)
Greentransfer	−0.0059*	−0.0055	−0.0037			
	(−1.6874)	(−1.0913)	(−0.8280)			
*treated*post*risk*				5.4637***	5.6305**	6.1593**
				(3.0525)	(2.1133)	(2.3794)
risk				0.2083	−0.4637	0.3070
				(0.1858)	(−0.2805)	(0.2211)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
_cons	3.5652***	3.4545***	3.4937***	3.5089***	3.2711***	3.4432***
	(29.2701)	(19.8034)	(23.1708)	(25.9522)	(16.8476)	(20.3664)
N	28,778	28,778	28,778	23,109	23,109	23,109
R^2	0.7774	0.8112	0.7080	0.7775	0.8112	0.7075

Note: See notes in Table 3.

strategic response to minimize the risks associated with compliance failures.

4.3.2 | Corporate Financial Difficulty

With reference to Ohlson (1980) and Liao et al. (2023), this paper measures firms' financial difficulty based on *Oscore*. We first calculate the *Oscore* score; the model is set up as follows.

$$\begin{aligned} OScore = & -1.32 - 0.407Size + 6.03Lev - 1.43Wc + 0.0757Cl - 2.37Nit \\ & - 1.83Cashflow + 0.285Int - 1.72Oen - 0.521Chin. \end{aligned} \tag{4}$$

In this model, *Size* denotes the size of the firm, expressed using the natural logarithm of the firm's total assets; *Lev* is the gearing ratio; *Wc* equals working capital/total assets; *Cl* equals current liabilities/current assets; *Nit* equals net profit/total assets; *Cashflow* equals net cash flow from operations/total liabilities. *Int* equals 1 if net profit is negative for the last 2 years, 0 otherwise; *Oen* equals 1 if total liabilities > total assets, 0 otherwise; *CHIN* equals $(NI_t - NI_{t-1})/(|NI_t| + |NI_{t-1}|)$; *NI* denotes net income.

Next, based on the above calculations, we would like that the practices that are differently scaled may be rescaled to the unit interval [0, 1]; so, in accordance with model (5), we calculate the corporate financial difficulty (*Risk*).

$$Risk = \frac{e^{OScore}}{1 + e^{OScore}}. \tag{5}$$

The regression results are presented in Columns (4)–(6) of Table 9. The results show that the coefficients of the interaction term *treated*post*risk* are all positive and significant at least at the 5% level, suggesting that heavily polluting firms' financial difficulty has led to an increase in the centralization effect of environmental policy shocks promoting its supply chain. This result is consistent with Hypothesis 3.

Our findings are consistent with previous research that financial constraints motivate firms to adopt more cost-effective and risk-averse supply chain strategies. For example, S. Wang, Zhang, et al. (2024) find how financial constraints affect firms' decision-making in green supply chain management, especially the preference for cost-effective strategies in the context of retailers' risk aversion. Similarly, Vanpoucke and Ellis (2020) find that firms increase supply chain resilience under financial constraints, favoring more secure supply strategies to reduce uncertainty. In the context of environmental policy shocks, our findings provide further empirical support for this view, highlighting that capital-strapped firms prefer centralized supply chains as a risk management strategy.

5 | Discussion

The mechanism analyzed in the previous section shows that the environmental policy shocks will promote the centralization of heavy polluters supply chain configuration under the influence of corporate green transformation and corporate financial difficulty. However, is there any significant difference in the supply chain management decisions of highly polluting enterprises under different heterogeneous characteristics? In this paper, we study whether there are differences in the environmental policy shocks on supply chain configuration under different circumstances from the perspective of enterprises' own characteristics and the influence of the external environment, respectively.

5.1 | Impact of the Dominant Position of the Enterprise's Resources

This paper reflects the enterprise's resource advantage status according to whether the enterprise is a state-owned enterprise (SOE) or not and conducts group examination. The results of the examination of SOEs and non-SOEs in Table 10 show that the coefficient of environmental policy shocks can be found to be more pronounced in the group of SOEs, driving the centralized configuration of the supply chain. Considering the importance of state-owned highly polluting enterprises to the economic system and the operation of the national economy, they have an advantageous position in obtaining resources such as financing lines, tax incentives, and policy support (Fan and Hope 2013). Therefore, in supply chain cooperation, SOEs are able to integrate and optimize supply chain resources more powerfully than non-SOEs, thus increasing the concentration of the supply chain. In addition, SOEs tend to occupy an important position in the market (Lioukas et al. 1993), and they can influence and guide upstream and downstream enterprises in the supply chain more effectively through the centralization strategy to promote the green development of the whole supply chain.

TABLE 10 | Heterogeneity test—Firm's resource advantage.

	(1)	(2)	(3)
VarName	***ST5r***	***CT5r***	***PT5r***
Panel A: State-owned corporate			
*treated*post*	0.0642***	0.0560**	0.0843***
	(3.7393)	(2.3538)	(3.7939)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
_cons	3.2788***	2.9068***	3.3643***
	(13.1283)	(8.2771)	(10.4847)
N	9381	9381	9381
R^2	0.7997	0.8237	0.7193
Panel B: Non–state-owned corporate			
*treated*post*	0.0209	0.0616***	0.0150
	(1.4425)	(2.8353)	(0.8766)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
_cons	3.7353***	3.7062***	3.5863***
	(24.6737)	(16.3267)	(19.4926)
N	19,372	19,372	19,372
R^2	0.7716	0.8094	0.7111

Note: See notes in Table 3.

5.2 | Impact of the Geographic Location of Corporate

This paper also examines whether environmental policy shocks have a heterogeneous effect on heavily polluting firms' supply chain concentration due to different geographical locations by dividing the firms in the sample into East, Central, and West regions. The result is shown in Table 11. From the overall perspective of the empirical results, the development of supply chain tendency towards centralization is more obvious for heavy polluters located in the eastern region after being hit by environmental policy shocks. Based on the result, we analyze the possible reasons: (1) Level of economic development: The higher level of economic development in the eastern region can provide more complete infrastructure and industrial chain support, which is conducive to heavy polluting enterprises to improve efficiency and respond to market changes through supply chain centralization (X. Zhang et al. 2024). (2) Industrial agglomeration effect: There is an obvious industrial agglomeration phenomenon in the eastern region, which helps the synergy effect among enterprises, reduces the production cost, and improves the innovation ability and market competitiveness (Ding et al. 2022). Thus, the effect of greater supply chain concentration in response to environmental policy shocks is more marked for highly polluting companies in the East.

5.3 | Impact of the Type of Resources on Which the Corporate Relies

In this paper, according to the 2012 industry classification standard of the China Securities Regulatory Commission, all the sample industries are classified into technology intensive, asset intensive, and labor intensive according to the intensity of production factors. The specific classification method is as follows: First, depending on the proportion of fixed assets, the higher proportion is classified as asset-intensive industries, which indicates that their capital is more significant; second, depending on the proportion of R&D expenditures to salaries, the larger proportion indicates that technology R&D is more critical to enterprises than labor factors, and thus belonging to technology-intensive industries, while the rest belong to labor-intensive industries. The results of this paper's classification of the industries in the sample are shown in Table A2.

The result is presented in Table 12. According to the empirical results, under the pressure of environmental policy shocks,

TABLE 11 | Heterogeneity test—Geographic location of corporate.

VarName	(1) *ST5r*	(2) *CT5r*	(3) *PT5r*
Panel A: Eastern region			
*treated*post*	0.0492***	0.0804***	0.0448***
	(3.7774)	(4.1571)	(2.7872)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
_cons	3.4382***	3.1558***	3.3890***
	(25.4840)	(16.0974)	(20.5282)
N	21,189	21,189	21,189
R^2	0.7872	0.8126	0.7292
Panel B: Western region			
*treated*post*	0.0429*	0.0110	0.0905***
	(1.6707)	(0.3155)	(2.7774)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
_cons	3.0852***	2.8800***	3.2907***
	(9.7515)	(6.7498)	(8.3760)
N	4479	4479	4479
R^2	0.7886	0.8404	0.6691
Panel C: Central region			
*treated*post*	−0.0031	0.0079	0.0011
	(−0.1129)	(0.2121)	(0.0303)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
_cons	4.6576***	4.9531***	4.5651***
	(11.6245)	(8.8029)	(7.6558)
N	3811	3811	3811
R^2	0.7402	0.7946	0.6567

Note: See notes in Table 3.

TABLE 12 | Heterogeneity test—The type of resources on which the corporate relies.

VarName	(1) *ST5r*	(2) *CT5r*	(3) *PT5r*
Panel A: Labor-intensive corporates			
*treated*post*	0.0455*	0.0464	0.0632**
	(1.8941)	(1.4056)	(2.3242)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
_cons	2.9115***	1.9897***	3.2742***
	(12.4184)	(5.5400)	(12.1087)
N	9636	9636	9636
R^2	0.7813	0.8099	0.7255
Panel B: Technology-intensive corporates			
*treated*post*	0.0332	0.0796*	0.0158
	(1.3033)	(1.8747)	(0.4564)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
_cons	3.6156***	3.7992***	3.3715***
	(22.8626)	(18.9732)	(15.7253)
N	14,133	14,133	14,133
R^2	0.7837	0.8156	0.7159
Panel C: Asset-intensive corporates			
*treated*post*	0.0458	−0.0505	0.0883
	(1.1571)	(−1.0257)	(1.6250)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
_cons	4.1632***	4.0600***	4.1405***
	(16.2169)	(11.9072)	(12.2683)
N	5247	5247	5247
R^2	0.8024	0.8427	0.6889

Note: See notes in Table 3.

the overall supply chain configuration of labor-intensive highly polluting firms has a tendency to the degree of concentration, in which the upstream supplier concentration rises significantly; while for technology-intensive highly polluting enterprises, the overall supply chain configuration tends to the effect of centralization that is not significant, and only the downstream customer concentration rises significantly. Finally, for asset-intensive highly polluting firms, there is no significant change in either upstream, downstream, or overall supply chain concentration.

Based on the results, we find that different types of heavily polluting firms adopt different coping strategies in the face of environmental policy shocks, depending on their characteristics and market conditions. Labor-intensive heavily polluting corporates may be more likely to reduce costs and risks through centralization, technology-intensive high polluting companies may concentrate more on innovation and market adaptation, and asset-intensive heavily polluting firms may focus more on maintaining existing stability and efficiency. Together, these factors lead to different types of heavily polluting firms showing different trends in supply chain concentration.

This finding is in line with existing research. For example, Song and Ding (2024) show that labor-intensive firms are more likely to adjust their supply chain configuration to reduce costs under environmental policy pressure, while technology-intensive firms are more likely to invest in R&D to enhance market competitiveness. In addition, Y. Lin and Li (2025) find that asset-intensive firms are more likely to stabilize their supply chains in response to policy changes in order to reduce operational volatility. Our study further complements the research in this area by showing that environmental policies not only affect firms' overall supply chain decisions but also have differential impacts on the supply chain adjustment paths of different types of firms.

6 | Conclusion

6.1 | Findings

The following four points are new findings of this paper. First, using a DID model as the baseline regression, we study the impact of environmental policy shocks on heavily polluting corporate supply chain configuration in 2015 using a sample of Chinese A-share listed companies from 2009 to 2022, which proves that environmental policy shocks have a positive impact on heavily polluting corporate supply chain centralization. Second, to analyze the intrinsic mechanism, we employ a DDD model, which reveals that corporate green transformation and corporate financial difficulty serve as key moderating factors, influencing the extent to which environmental policy shocks drive the centralization of supply chains among heavy polluters. Third, our heterogeneity analysis shows that the impact of environmental policy shocks to promote the development of heavily polluting corporate supply chain centralization varies according to the firm's resource dominance, the firm's geographic location, and the type of resources on which the firm relies. Specifically, the effects are more pronounced for highly resource-dominant heavily polluting firms, heavy polluters located in the eastern region, and labor-intensive highly polluting firms.

6.2 | Policy Recommendations

In view of the above research findings and analysis results, this paper, from the perspective of practical application, puts forward targeted policy recommendations from the perspectives of enterprises and policy makers, as a way to better promote the landing and optimization of environmental protection tax policies and to promote enterprises to fulfill their environmental responsibilities while realizing economic benefits.

6.2.1 | Policy Implications for Enterprises

The findings of this study reveal that under the pressure of environmental policy shocks, heavily polluting firms tend to adjust their supply chain structures towards greater centralization. While our findings indicate a trend towards supply chain centralization in response to environmental regulation, such structural shifts may warrant careful evaluation. Centralized supply chains, though efficient, could potentially increase exposure to supplier-specific risks, particularly in uncertain market environments. Firms should therefore assess the trade-offs between control and flexibility in their supply chain design decisions.

The analysis further shows that the degree to which firms centralize their supply chains in response to environmental regulation is significantly moderated by internal characteristics—namely, their green transformation capability and financial condition. Firms with a strong capacity for green innovation are more capable of leveraging supply chain restructuring as a strategic response, rather than a reactive measure. In contrast, firms experiencing financial difficulties may lack the resources or flexibility to implement balanced restructuring, potentially leading to inefficient or risk-prone decisions.

In the light of these findings, it is recommended that companies adopt supply chain restructuring as part of a broader long-term sustainability and risk management strategy. This includes adopting a formal supply chain risk assessment mechanism to identify critical vulnerabilities, assess the reliability and environmental compliance of key suppliers, and simulate potential disruptions. Companies should also consider developing contingency plans, including alternative suppliers, logistics routes, and production locations, to maintain operational resilience in the face of uncertainty. In addition, investments in digital supply chain tools and green technologies can simultaneously improve visibility, adaptability, and compliance. Importantly, supply chain decisions should be tailored to the specific financial and environmental capabilities of the enterprise in order to avoid overcentralization or underpreparation.

6.2.2 | Policy Implications for Policymakers

The findings of this study provide several insights for policymakers seeking to integrate environmental regulatory objectives with industrial adaptation and resilience. The finding that environmental policy shocks lead to significant supply chain restructuring in highly polluting firms—particularly towards more centralized configurations—suggests that regulatory signals can effectively drive organizational change. However, the nature and quality of these changes are inconsistent across firms and strongly constrained by internal capabilities and the external resource environment.

First, our mechanistic analyses suggest that firms with stronger green transformation capabilities are more likely to respond to regulatory pressures in a strategic and structured manner. In contrast, those facing financial distress are likely to exhibit more reactive or constrained forms of adjustment. Such differences imply that the effectiveness of regulation may be affected by the uneven capabilities of firms, especially in regions or industries with limited access to green technologies or capital. In such cases, policymakers should design complementary support mechanisms to bridge the adaptation gap. Targeted subsidies, tax incentives, or favorable green financing schemes could help capital-constrained firms adopt cleaner technologies and restructure their supply chains without compromising the resilience of their operations.

Second, the observed heterogeneity of firms' responses, driven by factors such as regional resource endowments, geographic location, and reliance on external inputs, highlights the limitations of a uniform, "one-size-fits-all" policy approach. Environmental regulation would benefit from greater environmental sensitivity, that is, policy intensity, implementation methods, and support tools vary by sector and region. For example, in less developed regions, more flexible compliance pathways could be tailored for SMEs, while in industrial centers, stronger incentives could be offered to accelerate green clustering effects.

Finally, in addition to firm-level support, system-level interventions are necessary to create an enabling environment for green supply chain transformation. This may include investments in regional green infrastructure, digital platforms for supply chain collaboration, and public–private partnerships promoting the diffusion of environmental innovation. By combining regulatory pressure with institutional support and structural flexibility, policymakers can improve environmental performance and enhance economic resilience and long-term industrial competitiveness.

6.3 | Directions for Future Research and Limitations

This study reveals the relationship between environmental policy shocks and firms' supply chain configurations through empirical analyses, providing preliminary research evidence in this area. However, this is still an exploratory study, and many issues still need to be further analyzed and explored in depth. Future research can be carried out in the following areas: (1) With the increased global focus on sustainable development, more and more firms have started to adopt green supply chain management strategies to cope with the increasingly stringent environmental policies and market demands. Future research can combine the dimensions of green innovation, carbon emission governance, and corporate social responsibility to analyze further how environmental policies affect enterprises' green supply chain transformation and explore the role of green supply chain management in enhancing enterprises' competitiveness and compliance. (2) This study focuses on the impact of the 2015 Environmental Protection Law on corporate supply chain configurations, but in reality, environmental policies are often shaped by a combination of policy instruments. For example, different tools such as the carbon emissions trading market, environmental taxes, government subsidies, and green financial policies may have different incentive or constraint effects on corporate supply chains. Therefore, future research can further explore the independent effects of different environmental policy instruments and their synergistic effects to provide a more comprehensive policy assessment framework and theoretical support for governments to formulate more precise environmental regulatory measures.

In addition, empirical evidence is provided by the research in this paper to illustrate the relationship between environmental policy shocks and firms' supply chain configuration, but it is still only starting research, and further in-depth analyses are needed. Firstly, the degree of firms' supply chain configuration is a comprehensive indicator involving multidimensional factors, and existing measurement methods all have advantages and disadvantages, so how to accurately measure the comprehensive configuration indicators of firms' supply chains is a direction for further research. Secondly, this study can only reflect the relatively short-term effects before and after policy shocks, and the long-term effects and enterprises' responses to environmental policies still need to be further analyzed.

Conflicts of Interest

The authors declare no conflicts of interest.

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Appendix

TABLE A1 | Keywords for green transformation of listed companies.

Category	Keywords
1	Green development, recycling development, low-carbon development, sustainable development, green building, recycling, low-carbon building, sustainable growth, low-pollution development, reduce energy consumption, improve resource utilization, improve recycling level.
2	Low-carbon life, green life, green production, green consumption, green finance, green governance, green construction.
3	Energy conservation, resource conservation, new energy development, ecological restoration, recycling, energy conservation and emission reduction, priority conservation, priority protection, natural restoration, and increased utilization.
4	Resource constraints, environmental pollution, ecological damage, resource depletion, ecosystem degradation, resource depletion, ecological damage, environmental risks, environmental protection pressure.
5	Biodiversity, ecosystem, ecological function, ecological service, ecological security, ecological protection, ecological restoration, natural ecology, species protection, care for the environment.
6	Environmental protection awareness, ecological protection awareness, ecological protection concept, ecological protection obligation, ecological environmental governance obligation, ecological commitment, environmental commitment, environmental protection obligation, environmental governance concept.
7	Environmental governance mode, comprehensive environmental governance, environmental remediation, environmental justice, social co-management, universal co-management, source prevention and control, environmental governance mode, environmental protection governance, ecological governance, ecological remediation, ecological prevention and control, pollution governance, pollution prevention and control.
8	Ecological civilization concept, ecological civilization system, ecological security mechanism, ecological risk prevention and control system, environmental governance system, environmental protection system, green technology innovation system, ecological compensation mechanism, green innovation, green technology, green upgrading, environmental protection upgrading, environmental protection transformation, low pollution transformation.
9	Ecological red line, green bottom line, respect nature, follow nature, protect nature.
10	Beautiful town, beautiful countryside, beautiful China, blue sky defense, blue water defense.
11	Environmental protection technology, governance technology, governance level, environmental protection efforts, ecological protection technology, corporate pollution prevention and control, corporate ecological protection, corporate environmental responsibility, corporate environmental responsibility, corporate ecological governance, corporate environmental governance, corporate green upgrading, corporate equipment upgrading, green development strategy, green upgrading strategy, green technology strategy, green innovation strategy.

TABLE A2 | Results by factor of production.

Industry	Technology intensive	Asset intensive	Labor intensive
Subindustry codes	N77 C36 M74 I65 C33 C35 C27 C29 C39 C38 C37 C41 C40	G56 D44 A04 B11 D45 B07 C22 C31 G55 C30 R86 C28 C26 C25	A01 A02 A03 A05 B06 B08 B09 C13 C14 C15 C17 C18 C19 C20 C21 C23 C24 C32 C34 D46 E48 E49 E50 F51 F52 G53 G54 G58 G59 I63 I64 K70 L72 M73 M75 N78 P82 R85 R87 S90

Note: Subindustry codes are derived from the 2012 Securities and Futures Commission Guidelines for Listed Companies by Segment.