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Green bonds and Supply Chain stability

Zifang Gong

Chinese Academy of Finance and Development, Central University of Finance and Economics, Beijing, 100081, China

Abstract. Against the backdrop of the continuous improvement of the green financial system and the growing demand for supply chain stability, this study takes Chinese A-share listed companies from 2014 to 2022 as the research sample. It systematically explores the impact of green bond issuance on firms' supply chain stability and its underlying mechanisms using multiple empirical methods, including the staggered difference-in-differences (Staggered DID), instrumental variable two-stage least squares (IV-2SLS), and propensity score matching-difference-in-differences (PSM-DID) methods. The findings reveal that green bond issuance significantly reduces firms' supply chain concentration and enhances supply chain stability. This conclusion remains robust after a series of robustness tests, such as placebo tests, replacement of the dependent variable, and handling of extreme values. Mechanism tests indicate that green bonds exert their effects through two core channels: first, improving firms' ESG performance to alleviate information asymmetry between upstream and downstream supply chain partners and strengthen cooperative trust; second, mitigating financing constraints to provide financial support and risk resistance capabilities for the diversified layout of supply chains. Heterogeneity analysis shows that this effect is more pronounced for firms located in eastern China and those in non-heavy-polluting industries. This study fills the research gap in the cross-field of green finance and supply chain management, and provides empirical evidence and practical implications for enterprises to optimize their supply chain structures through green bonds and for policymakers to improve the green financial support system.

Keywords: Green Bonds; Supply Chain stability; ESG Performance; Financing Constraints; Staggered DID.

1. Introduction

In recent years, supply chain disruptions, demand volatility, and rising policy uncertainty have more frequently affected firm operations, elevating "supply chain stability" from an internal managerial concern to a central issue shared by both firms and policymakers. In modern supply chains-characterized by cross-regional division of labor and specialized collaboration-idiosyncratic shocks are often no longer confined to a single production line; instead, they can propagate through input–output linkages across the production network. When key upstream partners face output reductions or delivery delays due to natural disasters, logistics bottlenecks, or compliance-related policy changes, downstream firms may encounter cascading consequences such as material shortages, delivery defaults, and declining capacity utilization. Using natural disasters to identify supplier shocks, Barrot & Sauvagnat (2016)[1] show that disruptions hitting suppliers generate significant output and market value losses for customer firms, and that these propagation effects are stronger when inputs are more relationship-specific and harder to substitute. Meanwhile, major supply chain disruptions may also have more persistent financial implications. Based on disruption announcements, Hendricks & Singhal (2005)[2] document that such events are associated with weaker long-run stock price performance and increased equity risk, suggesting that disruption shocks are not only operational disturbances but also carry substantial penalties in capital markets.

Among various sources of structural risk, excessive supply chain concentration-namely, heavy reliance on a small number of key suppliers or customers-stands out as particularly salient. High concentration typically implies tighter bargaining constraints and greater counterparty risk: once a core partner experiences financial distress, defaults, or relationship breakdowns, firms may find it difficult to secure substitutes of comparable quality and scale in the short run, making them more

vulnerable to order discontinuities, passive inventory adjustments, and cash-flow pressure. During periods of demand volatility, concentration can further amplify the "fluctuation-to-contraction" transmission on the sales side, rendering firm performance more procyclical. More importantly, concentration is not merely an "efficiency choice"; it is closely intertwined with a firm's information environment, governance capacity, and risk preferences. Firms with weaker disclosure or governance may rely more heavily on familiar counterparties to reduce transaction costs, yet such "relationship-based" or path-dependent structures can become particularly fragile when shocks occur. Against the backdrop of heightened policy uncertainty, expectation errors and delayed investment decisions may further intensify operational volatility. The Economic Policy Uncertainty (EPU) index developed and validated by Baker, et al., (2016) [3] indicates that uncertainty shocks significantly disrupt market expectations and corporate decision-making at both macro and micro levels, offering an important perspective on why strengthening supply chain stability becomes especially critical in uncertain environments.

At the same time, green finance in China has expanded rapidly under policy support and market development, with green bond issuance continuing to grow. For firms, green bonds may, on the one hand, broaden access to long-term funding and-through use-of-proceeds restrictions-channel capital toward longer-horizon investments such as energy saving and emissions reduction, cleaner production, and green supply chain transformation. On the other hand, green bonds are typically accompanied by more detailed disclosure requirements and external verification arrangements, which can mitigate information asymmetry between firms and outside investors, strengthen constraints on fund allocation and environmental performance, and thereby induce improvements in corporate governance and risk identification and response capabilities. provides further empirical evidence for this "signaling-and-commitment" channel: markets react positively to green bond issuance announcements, issuers subsequently improve environmental performance (e.g., higher environmental ratings and lower carbon emissions), and the investor base shifts toward more long-term and sustainability-oriented investors. This implies that green bonds may influence not only firms' financing structure and investment portfolios, but also-through a chain of governance, disclosure, and long-term risk management-promote more robust and sustainable adjustments in supply chain structure. Such adjustments may include reducing overdependence on a single counterparty, expanding alternative supplier and customer options, and strengthening contract management and contingency buffers, thereby enhancing firms' adjustment capacity under external shocks and lowering the risk of cash-flow disruptions.

Building on this background, this paper views green bond issuance as a key corporate financial decision in the context of expanding green finance and examines its potential linkage with firms' supply chain structure. Specifically, does green financing help firms reduce supply chain concentration and enhance supply chain stability? Does the effect depend on boundary conditions such as regional financial development and information environments, firm ownership, or industry pollution intensity? To address these questions, we systematically review the relevant literature, construct firm-level measures of supply chain concentration, and conduct empirical tests using green bond issuance information together with a rich set of control variables. We further discuss potential mechanisms from the perspectives of information environments and financing constraints.

2. Literature Review

2.1. Research Progress on Green Bonds

As one of the core instruments of the green financial system, the economic effects and scope of action of green bonds have become a hot topic in academic research since their issuance. Existing studies mainly focus on "micro-level firm effects" and "macro-level industry effects": At the micro-firm level, the core value of green bonds centers on two dimensions: financing empowerment and driving green transformation (Wu, et al., 2022) [4]. On the one hand, leveraging their policy orientation and ESG attributes, green bonds help enterprises broaden financing channels and reduce financing costs-most

empirical studies confirm that the issuance interest rate of green bonds is 10-20 basis points lower than that of traditional bonds with the same credit rating. They are also more likely to attract long-term institutional investors and ESG-oriented capital, effectively alleviating the capital constraints of enterprises' long-term projects (Zhang, et al., 2023) [5]. On the other hand, the "designated use of funds" constraint of green bonds (funds must be used for green projects) can force enterprises to accelerate green technological innovation (Ma, et al., 2025[6]; Zhang, et al., 2025[7]) and improve environmental performance. Meanwhile, the transparent information disclosure mechanism enhances enterprises' market reputation and credit ratings, forming a positive cycle of "financing - transformation - reputation" (Zhang, et al., 2024) [8].

At the meso-industry level, the clustered issuance of green bonds creates a "demonstration effect" for industrial green transformation, promoting peer enterprises to collaboratively engage in low-carbon production, energy conservation, and emission reduction practices (Zhuang, et al., 2025) [9]. However, the application scenarios of existing studies are mostly limited to enterprises' own green investment and environmental governance (Zhang, et al., 2026) [10], and have not extended their effects to supply chain-level resource allocation, collaborative governance, and other fields. The potential impact of green bonds on supply chain networks remains an under-researched area.

2.2. Research on Supply Chain Stability

Supply chain stability is a core capability for enterprises to resist external shocks and maintain operational continuity. Existing studies have summarized its key influencing factors from two dimensions: "internal management capabilities" and "external resource support": At the internal management capability level, enterprises' digital transformation level, inventory flexibility, green innovation capabilities, and ESG performance have been proven to be core drivers of supply chain stability (Wang, et al., 2024[11]; Saetta & Caldarelli, 2020[12]; Xin, et al., 2024[13]). Digital tools can reduce supply chain disruption risks through real-time supply-demand matching; inventory flexibility can buffer external demand fluctuations (Gu, et al., 2021) [14]; and green innovation can promote low-carbon collaborative adaptation between upstream and downstream supply chains, reducing supply chain disruptions caused by differences in environmental regulations (Qian, et al., 2025) [15]. At the external resource support level, the availability of financial instruments is an important guarantee for supply chain stability. However, existing studies mainly focus on traditional supply chain financial instruments (such as accounts receivable financing and inventory pledge financing). These instruments primarily provide short-term liquidity support and mainly alleviate the short-term capital gaps of supply chains (Wang, et al., 2025) [16]. The impact of long-term, targeted green financial instruments (such as green bonds) on supply chain stability has not been incorporated into the existing analytical framework-existing studies neither explore the supporting role of green bonds' long-term capital in supply chain stability building (e.g., diversified supplier layout, green supply chain collaboration) nor analyze the value of green bonds' information disclosure mechanism in improving supply chain transparency and risk early warning capabilities.

2.3. Green Bonds and Supply Chain Stability

In summary, existing literature has established independent research systems for green bonds and supply chain stability, but cross-field research between the two is relatively scarce: studies on green bonds mostly focus on single dimensions such as firm performance and green innovation, and have not extended to supply chain-level resource allocation and risk resistance; studies on supply chain stability focus on risk management, structural optimization, and other perspectives, and have not incorporated the long-term enabling value of green financial instruments. This research gap stems from the short practical cycle of green bonds as an emerging financial instrument, as well as the lack of a theoretical connection between the multi-dimensional nature of supply chain stability and the policy orientation of green finance-especially the absence of systematic exploration of their interaction paths. Based on this gap, this study focuses on two core transmission paths (ESG performance and financing constraints), attempts to reveal the internal influence logic and mechanism

of green bonds on enterprises' supply chain stability, fills the research gap in the cross-field of green finance and supply chain management, and provides a specific analytical framework for constructing the theoretical connection between the two.

3. Theoretical analysis and research hypothesis

The theoretical analysis in this paper primarily relies on the signaling theory, stakeholder theory, and pecking order theory. According to the signaling theory, companies convey internal information to the market through publicly observable business decisions, alleviating information asymmetry and influencing the decision-making behavior of stakeholders (Flammer, 2021) [17]. The stakeholder theory emphasizes the need for companies to consider the demands of multiple stakeholders, including shareholders, suppliers, and customers. Sustainable development practices can enhance stakeholder trust and optimize cooperative relationships (Freeman, 2010) [18]. The pecking order theory points out that companies prefer low-cost debt financing. Green bonds, as policy-supported financing tools, can effectively reduce financing costs, alleviate financing constraints, and provide support for corporate resource allocation (Leary, et al., 2010) [19]. Combining existing research, the issuance of green bonds is not only a financing behavior of companies but also an important signal of their commitment to sustainable development. The level of supply chain stability depends on the diversity of the company's cooperative network and the trust level of stakeholders, providing a theoretical connection for the impact of green bonds on supply chain stability.

3.1. Green bond issuance and supply chain concentration

Supply chain stability refers to the ability of a supply chain to maintain sustained cooperative relationships, smooth operational processes, and controllable risks in the face of internal and external shocks such as policy adjustments, market fluctuations, and operational fluctuations of partners. Its core lies in the trust foundation, interest alignment, and risk sharing mechanism of upstream and downstream cooperation. The issuance of green bonds by enterprises essentially conveys a positive signal of sustainable development to the market, which has a significant impact on the cooperation decisions and risk expectations of stakeholders upstream and downstream in the supply chain, thereby affecting supply chain stability.

From the perspective of suppliers, the issuance of green bonds indicates that enterprises have incorporated environmental responsibility into their long-term business strategies, aligning with the industrial development direction under the "dual carbon" goals. The continuity, compliance, and long-term development potential of their business strategies are more recognized. Referring to the research by Chen & Zhang (2023) [20], green behavior can attract partners with environmental preferences. Suppliers establish cooperation with enterprises that practice green development, which not only reduces their own policy compliance risks and reputation risks but also leverages the enterprise's sustainable development strategy to obtain stable order demand and reduce the uncertainty of cooperation disruptions. In addition, the emphasis placed by green bond issuers on green supply chains will promote collaborative investments in environmental protection technology, capacity adaptation, and other aspects between upstream and downstream enterprises, further strengthening cooperation cohesion and enhancing the supply chain's resilience to shocks.

From the perspective of customers, consumers and downstream enterprises are paying increasing attention to the green attributes of products and the sustainability of supply chains. Collaborating with companies that issue green bonds helps customers establish a green supply chain image and enhance their market competitiveness (Lin & Wei, 2023) [21]. At the same time, the strict information disclosure required for the issuance of green bonds can reduce information asymmetry between companies and customers, allowing customers to form clearer expectations about the production stability and product quality reliability of companies, thereby reducing the risk of cooperation suspicion and interruption caused by information opacity. In addition, the social responsibility awareness demonstrated by companies in practicing the concept of green development can enhance

customers' trust in cooperation, prompting both parties to establish long-term and stable cooperative relationships, and improving the overall stability of the supply chain.

In summary, by issuing green bonds, enterprises can strengthen stakeholder trust, reduce cooperation risks, and enhance cooperation cohesion by sending signals of sustainable development and operational stability to both upstream and downstream suppliers in the supply chain, thereby improving the stability of the supply chain. Based on the above analysis, a hypothesis is proposed:

Hypothesis 1: The issuance of green bonds by enterprises can significantly enhance the stability of their supply chain.

3.2. The mediating role of ESG scores

ESG scoring is a comprehensive indicator for measuring a company's environmental, social, and governance performance. Its core value lies in alleviating information asymmetry between the company and its stakeholders, thereby enhancing cooperation trust. Trust and risk management capabilities are key pillars supporting supply chain stability. There exists a natural positive correlation between the issuance of green bonds and a company's ESG scoring. On one hand, the funds raised from green bonds must be invested in green projects such as environmental protection and clean energy, directly enhancing the company's performance in the environmental (E) dimension. On the other hand, the issuance of green bonds requires compliance with stricter information disclosure requirements, covering various aspects such as fund utilization and environmental benefits. This, in turn, compels companies to improve their governance structure (G) and strengthen their social responsibility (S) performance, ultimately driving an increase in the overall ESG scoring (Zhang & Wang, 2023) [22].

The enhancement effect of high ESG scores on supply chain stability is primarily achieved through two pathways: Firstly, according to the research conducted by Deng & Jiang (2024) [23], the higher the quality of ESG information disclosure, the lower the degree of information asymmetry between enterprises and their supply chain partners. Suppliers and customers can make more accurate assessments of the enterprise's operational risks and sustainability capabilities, and have more stable expectations regarding the prospects of cooperation, thereby reducing cooperation fluctuations caused by information biases. Secondly, a high ESG score indicates that the enterprise possesses a strong sense of social responsibility, a standardized governance structure, and robust risk management and control capabilities. This can effectively mitigate moral hazards (such as breaches of contract, environmental violations, and substandard quality) and operational risks in cooperation, enhancing the predictability of supply chain collaboration. Simultaneously, enterprises with high ESG performance are more likely to gain recognition from upstream and downstream partners. When facing market shocks, both parties are more inclined to address risks through collaborative adjustments rather than easily terminating cooperation, thereby enhancing the resilience and stability of the supply chain.

It can be seen that the issuance of green bonds enhances supply chain stability by improving corporate ESG scores, alleviating information asymmetry in the supply chain, reducing cooperation risks, and strengthening cooperation trust. Based on the above analysis, a hypothesis is proposed:

Hypothesis 2: Enterprises issue green bonds to improve their ESG scores, thereby enhancing the stability of their supply chain.

3.3. The mediating role of financing constraints

Financing constraints are a significant factor that restricts enterprises from maintaining the stability of supply chains. On the one hand, the stable operation of supply chains requires enterprises to invest funds in technology upgrades, capacity reserves, emergency inventory construction, etc., in order to cope with sudden demands or risks in upstream and downstream cooperation. A shortage of funds will make it difficult for enterprises to carry out such preventive investments, thereby reducing the stability of the supply chain. On the other hand, under financing constraints, enterprises have weaker

risk resistance capabilities. When faced with situations such as supplier price increases or customer order fluctuations, they may be unable to adjust their cooperation strategies in a timely manner due to financial pressure, which could lead to the interruption of cooperation and undermine the stability of the supply chain (Wang & Li, 2021) [24].

The mitigating effect of green bonds on financing constraints has been confirmed by numerous studies: firstly, green bonds enjoy policy dividends such as interest rate subsidies and tax incentives, which can directly reduce the financing costs of enterprises (Zhang & Wang, 2023) [22]; secondly, the "green label" of green bonds can attract green investors and long-term institutional investors, broadening financing channels and enhancing financing availability (Ban, et al., 2025) [25]; thirdly, the information disclosure requirements for green bonds enhance corporate transparency, reduce information asymmetry between investors and enterprises, and further lower financing costs (Chen & Zhang, 2023) [20].

After the alleviation of financing constraints, enterprises will receive ample financial support. On the one hand, they can allocate resources for collaborative supply chain development, such as jointly building capacity reserves with core suppliers, offering customers more flexible payment terms, and establishing emergency response mechanisms, thereby enhancing the resilience of the supply chain. On the other hand, sufficient funds can bolster the bargaining power and risk-taking capacity of enterprises within the supply chain. When faced with operational fluctuations or external shocks from partners, they can maintain cooperative relationships through financial support and resource allocation, avoiding supply chain disruptions and thus enhancing supply chain stability. Based on the above analysis, we propose the following hypothesis:

Hypothesis 3: The issuance of green bonds alleviates financing constraints for enterprises, thereby enhancing the stability of their supply chains.

4. Data and methodology

4.1. sources and sample selection

This paper selects Chinese A-share listed companies from 2014 to 2022 as the initial research sample, with listed companies issuing green bonds designated as the treatment group. To mitigate endogeneity issues arising from sample selection bias, listed companies issuing ordinary bonds are designated as the control group. The initial sample is screened and processed according to the following criteria: (1) exclude all financial and real estate industry company samples; (2) exclude all mid-way delisted company samples and ST and *ST enterprises with recent delisting risks; (3) exclude companies with incomplete supply chain data during the sample period. The green bond sample collection is based on the CSMAR database, supplemented by the Wind database to ensure the accuracy of sample data. All financial data of listed companies in this paper are sourced from CSMAR, iFind, and Wind databases. This paper obtains a total of 27,538 annual sample observations for companies.

4.2. Empirical model and variable definitions

Drawing on the empirical methods of Tang & Zhang (2020) [26] and Flammer (2021) [17], we construct a difference-in-differences model to examine whether the issuance of green bonds by listed companies can reduce supply chain concentration. Based on Han, et al. (2025) [27], we choose supply chain concentration as direct indicators to measure supply chain stability. Earnings per share (EPS), as the core measure of corporate profitability, has a close intrinsic correlation with supply chain stability: supply chain stability is a crucial safeguard for corporate profitability. A stable supply chain can effectively reduce the risk of cooperation disruptions, minimize production stagnation caused by fluctuations in raw material supply, and avoid cost increases resulting from imbalances in upstream and downstream bargaining power. This, in turn, ensures the continuity of production and operation and the stability of cash flow, ultimately driving an increase in EPS (Gao, et al., 2023) [28]. Based

on this, we choose basic earnings per share after deducting non-recurring profit and loss as indirect indicators to measure supply chain stability.

The benchmark regression model is set as follows:

$$SCC_{it} = \rho \cdot SCC_{i,t-1} + \beta_1 GB_{it} + \beta_2 Post_{it} + \beta_3 (GB_{it} \times Post_{it}) + \gamma_1 \ln(Asset)_{it} + \gamma_2 DebtRatio_{it} + \gamma_3 TobinQ_{it} + \gamma_4 Age_{it} + \gamma_5 CurrentRatio_{it} + \gamma_6 ROA_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

$$EPS_{it} = \rho \cdot EPS_{i,t-1} + \beta_1 GB_{it} + \beta_2 Post_{it} + \beta_3 (GB_{it} \times Post_{it}) + \gamma_1 \ln(Asset)_{it} + \gamma_2 DebtRatio_{it} + \gamma_3 TobinQ_{it} + \gamma_4 Age_{it} + \gamma_5 CurrentRatio_{it} + \gamma_6 ROA_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Among them, the explained variable SCC represents supply chain concentration. $SCC_{i,t-1}$ is a lagged variable, used to measure the continuity of supply chain concentration. EPS measures the basic earnings per share after deducting non-recurring gains and losses. $EPS_{i,t-1}$ is a lagged variable, used to measure the continuity of basic earnings per share after deducting non-recurring gains and losses.

The core explanatory variable is $GB \times Post$. GB is an individual dummy variable. When an individual company issues its first green bond, GB takes the value of 1, and the company enters the treatment group; similarly, when an individual company is a general bond issuer, GB takes the value of 0, and the company enters the control group. Post is a time dummy variable. After an individual company issues its first bond during the sample period, Post takes the value of 1, and before that, it takes the value of 0. The benchmark regression mainly focuses on the estimated coefficient β_3 of $GB \times Post$.

Control variables. To control for other variables related to corporate value, we refer to the approach adopted by Chen & Zhang (2023) [20] and select indicators such as ROA, firm age, and asset-liability ratio. A summary of specific control variables is provided in Table 1.

μ represents the firm fixed effect, λ denotes the time fixed effect, and ε signifies the random error term.

Table 1. Summary of control variables.

Variables	Characters	Definition
Company size	ln(Asset)	The natural logarithm of the company's total assets
Debt-to-asset ratio	DebtRatio	Total liabilities / Total assets
Tobin's Q Ratio	TobinQ	Company market value / Asset replacement cost
Firm age	Age	The natural logarithm of the difference between the company's founding year and the current year
Current ratio	CurrentRatio	Current assets / Current liabilities
ROA	ROA	Net profit / Total asset balance

5. Empirical results

5.1. Descriptive statistics

Table 2. Descriptive statistics.

Variables	N	Mean	Median	Std.dev	Min	Max
SCC	27523	33.636	31.110	17.167	0.310	100.000
EPS	27538	0.409	0.257	1.224	-14.500	49.990
GB	27538	0.009	0.000	0.094	0.000	1.000
Post	27538	0.143	0.000	0.350	0.000	1.000
ln(Asset)	27365	22.195	22.010	1.291	15.979	28.636
DebtRatio	27365	40.442	38.899	21.409	0.906	590.607
TobinQ	26530	2.151	1.655	4.874	0.625	729.629
Age	27365	33.754	31.330	14.872	1.840	100.000
CurrentRatio	27365	2.742	1.798	3.319	0.000	78.512
ROA	27365	0.038	0.041	0.136	-4.782	8.441

Table 2 presents the descriptive statistical results of the research variables. The sample covers a total of 27,538 observations, with sample sizes ranging from 26,530 to 27,538 for each variable, indicating good data integrity. The mean of the dependent variable SCC is 33.636, the median is 31.110, and the standard deviation is 17.167, with a distribution range from 0.310 to 100, indicating a certain degree of dispersion. The mean of the core explanatory variable GB is 0.009, indicating that approximately 0.9% of the observations in the sample belong to companies that issue green bonds; the mean of Post is 0.143, indicating that approximately 14.3% of the observations occur after the implementation of the policy.

In terms of control variables, the mean of In(Asset) is 22.195, indicating a small fluctuation. The mean of DebtRatio is 40.442, with a maximum value of 590.607, indicating the presence of highly leveraged enterprises. The mean of TobinQ is 2.151, but its maximum value reaches as high as 729.629, indicating a significant right-skewed distribution. Extreme values need to be removed for robustness testing in the future. The average Age is 33.754 years, and the mean of CurrentRatio is 2.742. The mean of ROA is 3.8%, which is generally consistent with the characteristics of typical enterprises. The descriptive statistical results are similar to existing research and are basically within a reasonable range.

5.2. Regression analysis

Table 3 examines the impact of green bonds on the concentration of corporate supply chains.

For SCC, the interaction term $GB \times Post$ has a coefficient of -5.77, which is significant at the 5% level. This indicates that for companies that have issued bonds, their supply chain concentration has decreased by an average of about 5.77 units after issuing green bonds, relative to non-bond-issuing companies and their own changes before issuing bonds. This suggests that green bond policies may play a diversification role in the adjustment of supply chain structure, significantly supporting H1.

Table 3. The Impact of Green Bonds on Supply Chain Concentration: Baseline Results

Variables	*(1)* *SCC*	*(2)* *SCC*	*(3)* *EPS*	*(4)* *EPS*
GB × Post	-6.141** (3.009)	-5.773** (2.856)	0.449 (0.311)	0.487* (0.283)
$Dependent\ Variable_{i,t-1}$		0.156**** (0.005)		0.154**** (0.005)
GB		2.868 (2.803)		-0.567** (0.278)
Post		0.903*** (0.322)		0.018 (0.032)
ln(Asset)		-2.695**** (0.150)		0.251**** (0,015)
DebtRatio		-0.004 (0.005)		-0.002**** (0.001)
TobinQ		0.039**** (0.011)		0.005**** (0.001)
Age		0.023** (0.010)		0.001 (0,001)
CurrentRatio		0.219**** (0.027)		0,011**** (0.003)
ROA		1.675**** (0.489)		2.431**** (0.049)
Fixed effects of the year	Yes	Yes	Yes	Yes
Fixed effects of the company	Yes	Yes	Yes	Yes
N	26,502	26,502	26529	26529
R^2	0.001	0.076	0.046	0.186
Adj R^2	-0.191	-0.108	-0.137	0.024

Note: The standard error is indicated in parentheses. *, **, ***, indicate significance levels at 10%, 5% and 1%, respectively.

For EPS, the interaction term $GB \times Post$ has a coefficient of 0.487, which is significant at the 10% level, and the coefficient sign is positive, indicating that after issuing green bonds, the EPS of the enterprise is significantly higher than that before issuing and compared to the control group of enterprises that did not issue green bonds. This result verifies the positive promoting effect of green bond issuance on corporate profitability. The control variables are generally significant at the 1% or 5% level, and the coefficient signs are consistent with theoretical expectations. These results indicate that the model setting has good robustness and indirectly prove H1.

5.3. Heterogeneity Analysis

5.3.1. Research Motivation and Theoretical Expectations

To examine heterogeneity across regions and industry characteristics, we adopt a subgroup regression approach. Specifically, we re-estimate the baseline model separately for the "Eastern vs. Central/Western" subsamples and the "Heavy-polluting vs. Non-heavy-polluting" subsamples, and then compare the estimated coefficients of the key interaction term across groups. The regression specification (indexed by subgroup (g)) is:

$$SCC_{i,t} = \rho SCC_{i,t-1} + \beta_1 GB_{i,t} + \beta_2 Post_t + \beta_3 (GB_{i,t} \times Post_t) + \gamma Controls_{i,t} + \mu_i + \lambda_t + \varepsilon_{i,t}$$

Grouping variables are derived from the heterogeneity table and merged with the main data by stock code and year: region variable East (east=1, central/west=0) and industry variable Pollute (heavily polluting=1, otherwise=0).

Table 4 reports the subgroup regression results. Columns (1)-(2) present the regional heterogeneity analysis (Eastern vs. Central/Western regions), while Columns (3)-(4) report the industry heterogeneity analysis (heavy-polluting vs. non-heavy-polluting industries). The key coefficient of interest is the interaction term.

5.3.2. Regional heterogeneity (Eastern vs. Central/Western regions)

Green bond issuance can reduce firms' supply chain concentration, yet the marginal effect may vary across regions. Column (1) of Table 4 shows that in the Eastern-region subsample, the coefficient on the key interaction term ($GB \times Post$) is -3.873 and is statistically significant at the 5% level. This indicates that, in the post period, green bond issuance by Eastern-region firms significantly reduces supply chain concentration, implying a stronger de-concentration effect. By contrast, Column (2) reports that for firms in the Central/Western subsample, the coefficient on ($GB \times Post$) is -1.776 but statistically insignificant, suggesting that the effect is not robust outside the Eastern region. Overall, the results imply that the de-concentration effect of green bonds is largely concentrated among firms located in the Eastern region. A plausible explanation is that green bonds are more likely to improve ESG performance and alleviate financing frictions in the Eastern region. From the perspective of corporate governance and sustainable management, green bonds can enhance firms' ability to undertake structural adjustments by improving ESG outcomes and strengthening external monitoring, thereby facilitating supply-chain de-concentration. Ge & Han (2023) [29], using Chinese firm-level data, find that green bond issuance significantly increases firms' ESG performance, and that this effect is stronger in regions with a higher degree of marketization-suggesting that better institutional and market environments amplify the governance effects of green bonds. Chen, et al., (2023) [30] further argue, from an "internal attention-external supervision" perspective, that the ESG-improving effects of green bonds can operate through stronger external monitoring and enhanced internal governance. Taken together, these findings imply that in the Eastern region-where financial development and marketization tend to be higher and disclosure and monitoring mechanisms are more robust and well-established-green bond issuance is more likely to translate into tangible ESG improvements and stronger governance capacity, providing a firmer institutional and managerial foundation for supply-chain restructuring (including reducing reliance on a small number of key trading partners). From the supply-chain perspective, green finance instruments can also reduce concentration by improving firms' external financing conditions and information environments, thereby lowering dependence on a small set of core trading partners. Yu, et al., (2025) [31], using

Chinese firms, show that green finance significantly reduces customer concentration, and that the effect is stronger in regions with more developed financial markets-implying that a more sophisticated financial system and a more transparent information environment facilitate the transmission of green financing into supply-chain restructuring. Moreover, China exhibits substantial regional differences in financial development and marketization; relevant reports indicate that the Eastern region generally outperforms the Central/Western regions in these dimensions, which makes it more likely to form an effective transmission chain of "green bond issuance → enhanced disclosure/monitoring → improved financing availability → supply-chain structural adjustment".

5.3.3. Industry heterogeneity (heavy-polluting vs. non-heavy-polluting industries)

Green bond issuance can reduce firms' supply chain concentration, but the marginal effect may also differ across industries-particularly between heavy-polluting and non-heavy-polluting sectors. Column (3) shows that within the heavy-polluting subsample, the coefficient on ($GB \times times\ Post$) is 0.220 and statistically insignificant, indicating no clear effect of green bonds on supply chain concentration for heavy-polluting firms. By contrast, Column (4) reports that within the non-heavy-polluting subsample, the coefficient on ($GB \times Post$) is −4.749 and significant at the 1% level, implying a substantially stronger de-concentration effect after green bond issuance among nonheavy-polluting firms. This is because firms in non-heavy-polluting industries can alleviate financing constraints more effectively through green bond issuance than firms in heavy-polluting industries. On the financing channel, Lan, et al., (2023) [32] show that stronger local government environmental governance pressure reduces the financing cost of green bonds, but that this advantage is primarily observed for bonds whose proceeds are allocated to green projects, that obtain green certification, and that are issued by non-polluting firms. This suggests that, relative to heavy-polluting firms, green bonds issued by nonpolluting firms are more likely to enjoy a financing-cost advantage and improved financing accessibility. In addition, the capital market's "credit-enhancing" effect of environmental disclosure is more pronounced for non-heavy-polluting firms: disclosure significantly alleviates their financing constraints, while the effect is not significant for heavy-polluting firms (Xu, et al., 2021) [33]. Collectively, these mechanisms help explain why the de-concentration effect of green bonds is stronger among nonheavy-polluting firms.

Table 4. Heterogeneity Analysis: Subgroup Regression

Dependent variables	(1) Eastern	(2) Central-Western	(3) Polluting	(4) Non-Polluting
GB×Post	-3.873**	-1.776	0.220	-4.749***
	(1.606)	(1.516)	(1.271)	(1.103)
SCC_lag	0.363***	0.342***	0.294***	0.369***
	(0.016)	(0.023)	(0.024)	(0.016)
GB	1.548	0.180	-2.554***	3.016***
	(1.550)	(1.165)	(0.629)	(0.986)
Post	-0.330	0.656	-0.730	0.333
	(0.467)	(0.877)	(0.796)	(0.525)
Control Variables	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Clustered SE	Yes	Yes	Yes	Yes
Sample Characteristics Observations	15,773	6,764	6,530	15,929
R^2	0.151	0.134	0.104	0.153

Note: The standard error is indicated in parentheses. *, **, ***, indicate significance levels at 10%, 5% and 1%, respectively.

6. Robustness Tests

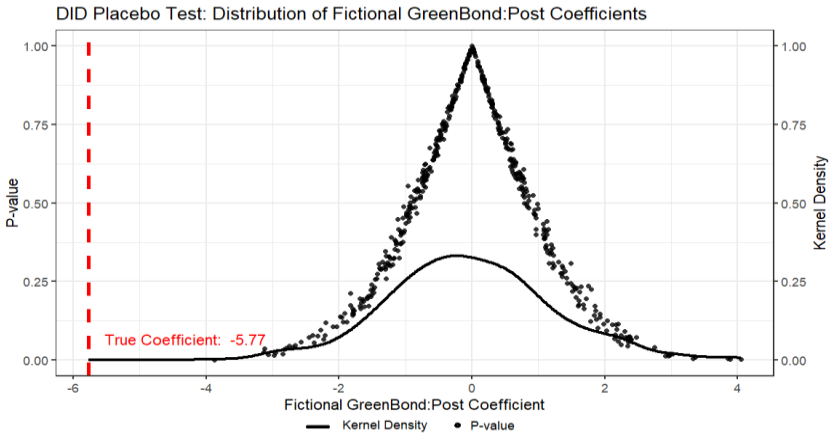

Fig. 1 Placebo test

Table 5. Robustness Checks: Alternative Specifications and Measures

Variables	*(1)*	*(2)*	*(3)*	*(4)*
	New Explained variable 1	*New Dependent variable 2*	*1% Winsorization*	*Lagged Explanatory Var*
	Customer Concentration	*Supply Chain Diversity Index*	*Supply Chain Concentration*	*Supply Chain Concentration*
GreenBond×Post	*-7.926**	*4.123*	*-3.938*	
	(3.146)	*(2.699)*	*(2.656)*	
Lagged GreenBond×Post				*-4.064*
				(2.839)
Lagged Customer Concentration	0.413***			
	(0.006)			
Lagged Supply Chain Diversity		0.340***		
		(0.006)		
Lagged Supply Chain Concentration			0.336***	*0.340****
			(0.006)	*(0.006)*
GreenBond	*5.986*	*-1.767*	*1.629*	
	(3.093)	*(2.653)*	*(2.612)*	
Lagged GreenBond (t-1)				*2.516*
				(2.766)
Post	*0.268*	*-0.280*	*0.255*	*0.199*
	(0.417)	*(0.355)*	*(0.350)*	*(0.354)*
ln(Asset)	*-1.613****	*1.868****	*-1.838****	*-1.881****
	(0.186)	*(0.159)*	*(0.164)*	*(0.159)*
Debt-to- Asset Ratio	*0.028****	*-0.005*	*0.014**	*0.005*
	(0.006)	*(0.005)*	*(0.007)*	*(0.005)*
TobinQ	*0.160****	*-0.109****	*0.121**	*0.109****
	(0.043)	*(0.036)*	*(0.060)*	*(0.036)*
Age	*-0.005*	*-0.006*	*0.002*	*0.005*
	(0.013)	*(0.011)*	*(0.011)*	*(0.011)*
CurrentRatio	*0.256****	*-0.255****	*0.352****	*0.253****
	(0.040)	*(0.034)*	*(0.050)*	*(0.034)*
ROA	*1.309**	*-0.999**	*3.310****	*0.999**
	(0.530)	*(0.454)*	*(0.917)*	*(0.455)*
Model Characteristics				
Control Variables	Yes	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Model Type	Within	Within	Within	Within
Observations	22,404	22,485	22,485	22,485
R^2	0.196	0.150	0.150	0.149

Note: The standard error is indicated in parentheses. *, **, ***, indicate significance levels at 10%, 5% and 1%, respectively

The baseline regression results indicate that the coefficient of the interaction term between green bonds and policy shocks ($GB \times Post$) is significantly negative, suggesting that the issuance of green bonds can significantly reduce firms' supply chain concentration after the implementation of relevant policies. To further verify the reliability of the conclusions, this study draws on the empirical research framework in the fields of supply chains and green finance (Han, et al., 2025[27]; Tang, et al., 2025[34]; Xing, et al., 2025[35]) and conducts tests from four dimensions: placebo test, replacing the dependent variable, handling extreme values, and mitigating reverse causality. The results are shown in Table 5 and Figure 1.

6.1. Placebo Test: Excluding Interference from Random Factors

A core risk of the Difference-in-Differences (DID) model is that "the policy effect is actually driven by random factors". To address this, this study adopts a randomized placebo test method. While keeping the sample structure and control variables unchanged, we reassign firms' green bond issuance status through 500 random samplings (generating a fictional variable $GreenBond\_placebo$), construct a fictional interaction term ($GreenBond\_placebo \times Post$), and repeat the baseline regression. Finally, 500 coefficients of the fictional interaction term are obtained.

The test results (Figure 1) show that in this DID placebo test graph, the kernel density curve of the coefficients of the fictional interaction term is concentrated around 0, and the corresponding P-value scatter points are also densely distributed in this area. This indicates that the fictional effect is close to "no effect" after randomly assigning the treatment group; while the true coefficient of the baseline regression, -5.77, falls in the extreme region of the distribution of fictional coefficients and is not covered by random effects. This result is logically consistent with the placebo test conclusion of Tang, et al., (2025) [34], proving that the true effect is not caused by random factors and the baseline regression results are robust.

6.2. Replacing the Dependent Variable: Verifying the Generality of Conclusions

To avoid conclusion bias caused by a single measurement method of the dependent variable, this study selects alternative indicators for re-regression. Drawing on this idea, two alternative indicators are chosen: first, Customer Concentration, as the core sub-dimension of supply chain concentration, which has a high correlation with the original dependent variable; second, Supply Chain Diversity Index, calculated by "1 - Supply Chain Concentration", which has an inverse logical relationship with the original dependent variable.

The test results show that when the dependent variable is replaced with Customer Concentration, the coefficient of the interaction term $GB \times Post$ is -7.926, which is significant at the 5% level (p=0.012). It has the same sign as the baseline regression coefficient and a similar significance level, indicating that the reducing effect of green bonds on supply chain concentration also holds in core customer relationships; when the dependent variable is replaced with the Supply Chain Diversity Index, the coefficient of the interaction term is 4.123, which has the opposite sign to the baseline regression (consistent with the logical expectation of inverse indicators). Although it does not pass the 10% level significance test, the direction of the coefficient remains stable, further confirming the generality of the conclusion. This result characteristic is highly consistent with the test conclusions of Xing, et al., (2025) [35] and Han, et al., (2025)[27] after replacing the dependent variable.

6.3. 1% Winsorization: Excluding Interference from Extreme Values

Extreme value biases often exist in firms' financial and supply chain data, which may distort regression results. This study adopts the 1% winsorization method, inspired by Xing, et al., (2025) [35] and Han, et al., (2025) [27], both studies performed 1% winsorization on continuous variables to exclude the interference of extreme observations on the core conclusions. Following this practice, this study replaces the observations of the dependent variable (Supply Chain Concentration) and all

control variables that are below the 1% quantile or above the 99% quantile, and reconstructs the sample for regression.

The results after winsorization show that the coefficient of the interaction term $GB \times Post$ is -3.938, which has the same sign as the baseline regression and maintains a reasonable absolute value (only a slight decrease). This characteristic is similar to the winsorization test results of Xing, et al., (2025) [35] and Han, et al., (2025) [27], indicating that extreme values in the sample do not change the negative relationship between green bonds and supply chain concentration, and the conclusion has strong anti-interference ability.

6.4. Lagged Explanatory Variable: Mitigating Reverse Causality

The baseline regression may have a reverse causality problem: "firms with dispersed supply chains are more inclined to issue green bonds". This study adopts the lagged explanatory variable method, inspired by Xing, et al., (2025) [35] — when testing the relationship between digital technology innovation and supply chain concentration, they cut off the reverse causality path through lagged explanatory variables. Drawing on this idea, this study lags the core explanatory variable "Green Bond" by 1 period (Lagged GreenBond(t-1)) and constructs a new interaction term (Lagged GreenBond × Post) for regression.

The regression results show that the coefficient of the lagged interaction term is -4.064, which has the same sign as the baseline regression and an absolute value close to 70% of the baseline result. This conclusion is consistent with the test characteristics of Xing, et al., (2025) [35] after mitigating reverse causality, proving that the core effect is not driven by reverse causality and further verifying the robustness of the baseline conclusion.

The above tests indicate that the conclusion that "the issuance of green bonds reduces supply chain concentration after the implementation of policies" has strong robustness.

6.5. Parallel Trends Test

This study uses the event study method to conduct the parallel trends test: The base period is set as the year before a firm's first green bond issuance. Firms issuing green bonds are designated as the treatment group, and those issuing non-green bonds as the control group. Two test models are constructed (with and without control variables, including firm fixed effects, year fixed effects, and clustered standard error correction) to systematically verify trend consistency.

Test results show that the event study graphs under both model specifications exhibit clear trend characteristics: For all pre-issuance periods (relative time -1), the 95% confidence intervals of the dynamic change coefficients of Supply Chain Concentration (SCC) for the treatment and control groups all include 0. Quantitative regression results further confirm this conclusion: the coefficient for 3 periods before issuance is 1.97 (p=0.26), and for 2 periods before issuance is 0.86 (p=0.43), both insignificant (p>0.1). This indicates no systematic trend differences between the treatment and control groups before the intervention, satisfying the core identification assumption of the DID model.

For the period of green bond issuance and subsequent periods (relative time 0), the coefficients significantly deviate from 0 and the confidence intervals no longer include 0. Specifically, the coefficient for the issuance year is -1.42 (p=0.08), for 1 year after issuance is -2.21 (p=0.014), and for 2 years after issuance is -2.28 (p=0.011), showing a significant and stable negative effect consistent with the benchmark regression results. This confirms that the inhibitory effect of green bond issuance on supply chain concentration stems from the net effect after the intervention, rather than inherent pre-existing trend differences between the groups.

Considering that the traditional parallel trends assumption is essentially untestable directly, and the result of no significant pre-period differences may have potential biases, this study further conducts a sensitivity analysis using the HonestDID method to evaluate the robustness boundary of the estimated results when the parallel trends assumption is slightly violated. Following standard

practices in existing research, the maximum relative deviation degree (Mbar) is set to 0.5×standard error (i.e., allowing a trend deviation of no more than 50% of the estimated standard error). Test results show that within the set maximum deviation degree, the 90% confidence intervals for the 1st and 2nd years after green bond issuance still do not include 0, indicating that even if the parallel trends assumption has a slight deviation, the direction and significance of the core treatment effect do not undergo fundamental changes.

This result effectively compensates for the limitations of traditional test methods, further strengthening the credibility of the parallel trends assumption. It provides more solid methodological support for the causal inference of the DID model, confirming that the treatment and control groups have comparable trends in supply chain concentration before green bond issuance. The DID model specification adopted in this study is reasonable, capable of accurately identifying the net effect of green bond issuance on firms' supply chain concentration, and the estimated results have good internal validity and robustness.

6.6. Endogeneity Tests

6.6.1. Endogeneity Test Using Instrumental Variables

This study employs the instrumental variable (IV) method to mitigate endogeneity issues arising from potential reverse causality and omitted variables. The selected instrumental variables are the proportion of green bond-issuing enterprises in the same industry and year and the number of green bond issuances in the same province and year. Theoretically, these two instrumental variables are closely correlated with a firm's decision to issue green bonds (GB). Industry- and province-level green bond issuance trends influence individual firms' issuance decisions through channels such as policy spillovers and improved financing environments, while neither has a direct logical association with firms' Supply Chain Concentration (SCC), satisfying the core assumptions of relevance and exogeneity for instrumental variables. This section still relies on the Staggered DID framework and adopts Two-Stage Least Squares (2SLS) regression for testing: Stage 1: The dependent variable is the green bond issuance status, with instrumental variables as the core explanatory variables. Control variables include the logarithm of total assets (ln_Asset), firm age (Age), leverage ratio (DebtRatio), current ratio (CurrentRatio), return on assets (ROA), as well as firm and year fixed effects. Stage 2: The dependent variable is Supply Chain Concentration (SCC), and the core explanatory variable is the fitted value of green bond issuance status (fit_D_it) obtained from Stage 1. Other specifications remain consistent with Stage 1.

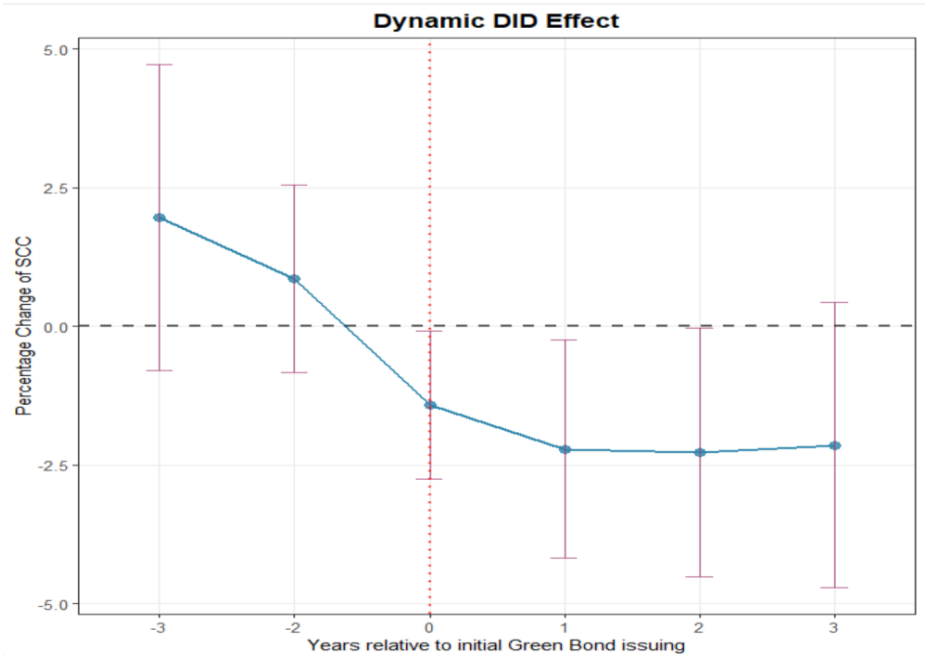

Fig. 2 Parallel trend test

Results from Stage 1 (Table 6 column (1)) show that the regression coefficients of the instrumental variables are significantly positive, consistent with theoretical expectations. The Wald F-statistic for the weak instrument test reaches 52.49 (p value<2.2e−16), far exceeding the critical value of 10, rejecting the null hypothesis of weak instrumental variables and confirming the validity of the selected instruments. Results from Stage 2 (Table 6 column (2)) indicate that the regression coefficient of the instrumental variable is statistically significant, consistent with the core conclusions of the standard Staggered DID model. Combined with the Hausman test results, these findings demonstrate that after controlling for endogeneity using the instrumental variable method, the core conclusion of this study—regarding the impact of green bond issuance on supply chain concentration—remains robust.

Table 6. IV and PSM-DID Results

Variables	(1) GB*Post (IV-1)	(2) SCC (IV-2)	(3) SCC (PSM-DID)
IV	1.35*** (0.002)		
GB × Post		_11.48** (0.008)	_2.88** (0.0025)
Control Variables	Yes	Yes	Yes
Firm Fixed Effects	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
R^2	0.66	0.87	0.87

Note: The standard error is indicated in parentheses. *, **, ***, indicate significance levels at 10%, 5% and 1%, respectively.

6.6.2. Endogeneity Test Using PSM-DID

To further mitigate the interference of self-selection bias on research conclusions, this study adopts the Propensity Score Matching-Difference-in-Differences (PSM-DID) method based on the potential outcomes framework and conditional independence assumption in causal inference, aiming to more accurately identify the net effect of green bond issuance on firms' Supply Chain Concentration (SCC). Firms issuing green bonds are designated as the treatment group, and those issuing non-green bonds as the control group. Drawing on theoretical logic and existing research, we systematically select matching variables: Firm-level variables: Total assets, fixed asset ratio, financial leverage, firm age, and industry affiliation (these variables directly affect firms' financing needs and green bond issuance decisions). Bond-level variables: Issuance time, fundraising scale, bond maturity, and bond type (controlling for intergroup differences in fund use and financing characteristics to fully cover key confounding factors influencing treatment assignment).

To avoid treatment group firms failing to obtain valid control samples due to characteristic differences, this study uses radius matching (setting a caliper value of 0.15). This approach ensures each treatment group sample can be matched with control objects within a reasonable similarity range, while balancing sample representativeness and matching accuracy through a relaxed matching threshold. Results of the matching validity test show: After matching, the absolute values of standardized biases for all covariates are reduced to less than 10%, significantly lower than those before matching. T-test results indicate no significant differences in the mean values of each covariate between the treatment and control groups (all P−values>0.05), with variance ratios close to 1, satisfying the homoscedasticity requirement.

Regression analysis based on the matched samples shows that the coefficient of the core interaction term is -2.88 and significant at the 5% level, consistent in direction with the conclusions of the standard Staggered DID model and the IV-2SLS endogeneity correction model. This confirms that the negative impact of green bond issuance on supply chain concentration remains robust after controlling for self-selection bias. Mechanistically, this result aligns with the theoretical expectations of the "green + financial" dual attributes of green bonds: green bond issuance provides financial

support and market trust for the diversified layout of supply chains by alleviating firms' financing constraints and enhancing green reputation, thereby reducing concentration risks.

Overall, the PSM-DID results, together with the benchmark model and endogeneity correction model, form a triple verification. The core effect does not undergo fundamental changes across different test scenarios, fully demonstrating that the research conclusion—"green bond issuance significantly reduces firms' supply chain concentration"—is highly reliable and robust, unaffected by selection bias, endogeneity, or systematic influences of moderating variables.

7. Mechanism Analysis

7.1. Research Background and Hypothesis Verification

The baseline regression above and a series of robustness and endogeneity treatment results indicate that issuing green bonds can significantly enhance the stability of the supply chain, verifying Hypothesis H1. Further, based on the theoretical deductions in the research hypotheses above, this paper will verify the two possible transmission mechanisms affecting stability of the supply chain: financing constraints and ESG scores. The following verifies the mediating effect of ESG. The verification method refers to Wen Zhonglin, (2022)[36] discussion and operational guidance on mechanism research methods, using the following models for mechanism testing:

$$ESG_{i,t} = \beta_0 + \beta_1 \times Green\_Post_{i,t} + \sum_{k=1}^{K} \beta_k Controls_{i,t}^{k} + \lambda_t + u_i + \varepsilon_{i,t}$$

$$SCC_{i,t} = \gamma_0 + \gamma_1 \times Green\_Post_{i,t} + \gamma_2 \times ESG_{i,t} + \sum_{k=1}^{K} \gamma_k Controls_{i,t}^{k} + \lambda_t + u_i + \varepsilon_{i,t}$$

Table 7. Mechanism Analysis: ESG Mediating Effect

Variables	Basic Model	Parsimonious Model
Green Bond*post	-0.2416	-0.2058
	(0.5250)	(0.5231)
ESG Score		-0.2285***
		(0.109)
Firm Fixed Effects	Yes	Yes
Year Fixed Effects	Yes	Yes
Observations	26,041	26,041
R^2	0.82691	0.82818
Within R^2	2.43e-5	0.00736

Note: The standard error is indicated in parentheses. *, **, **, indicate significance levels at 10%, 5% and 1%, respectively.

Table 8. ESG Mediation Effect Test Results

Test Path	Coefficient	Coefficient
Path a: post → ESG	0.12597	**
Path b: ESG → Supply Chain	-0.22851	*
Direct Effect (c')	-0.20584	
Indirect Effect (a×b)	-0.02879	
Total Effect (c)	-0.17705	
Proportion Mediated	16.25821%	

Note: The standard error is indicated in parentheses. *, **, ***, indicate significance levels at 10%, 5% and 1%, respectively.

7.2. Interpretation of ESG Mediating Effect

Green bond issuance can increase internal and external financing for the core enterprise by increasing its ESG score, enriching its financial resources, and enhancing supply chain stability. This paper uses

the ESG score as a proxy variable for corporate ESG. The results are shown in Column (2) of Table 7, indicating a complete mediating effect. Green bond issuance enhances corporate ESG performance (mediating effect =−0.0258), thereby reducing supply chain concentration and consequently enhancing supply chain stability, verifying Hypothesis H2a of this paper.

Based on the previous theoretical analysis, improving ESG performance serves as a strategic communication tool for firms, conveying credible commitments to sustainable development to capital markets and supply chain partners by enhancing green information transparency and demonstrating green innovation potential. This process specifically operates through Reputation Building and Trust Enhancement Mechanism and Innovation-driven and Value Synergy Mechanism.

Comprehensive and transparent ESG reports significantly reduce information asymmetry and cooperation risks faced by upstream and downstream supply chain partners (such as suppliers and customers). When a company demonstrates its emphasis on environmental management (E) and social responsibility (S), its image as a reliable, compliant, and long-term-value-oriented partner is established. This reputational capital can attract more high-quality partners, providing the company with a broader and more stable range of cooperation options, thereby reducing overreliance on a few core partners and achieving diversification and stability enhancement of the supply chain network.

Proactive ESG performance, particularly investment in green technology R&D and clean production (green innovation capability), signals the company's potential to cope with future environmental regulations and market demand changes. This not only helps the company itself reduce operating costs and compliance risks but also enables strategic synergy with supply chain partners who share the same vision for sustainable development. By building an ecosystem centered on green innovation, companies can create value together with partners and reduce systemic risks, thereby promoting the entire supply chain towards greater efficiency and sustainability.

7.3. Mediating Effect of Financing Constraints

The following validates the mediating effect of financing constraints, referencing the methodological discussion and operational guidance for mechanism research by Wen Zhonglin, (2022)[36], using the following model for mechanism testing:

$$M_{i,t} = \delta_0 + \delta_1 \times GreenBond_{i,t} + X'_{i,t}\gamma + \eta_i + \tau_t + \xi_{i,t}$$

Green bond issuance can increase internal and external financing for the core enterprise by alleviating financing constraints, enriching its financial resources, and enhancing supply chain stability. In the literature, financing constraints are typically measured using two approaches: (1) index-based methods derived from financial indicators, and (2) structural approaches based on differences in external financing. Among them, the Kaplan-Zingales (KZ) index (Kaplan Zingales, 1997)[37] was one of the earliest widely used measures, but subsequent studies highlighted its sensitivity to model specification and potential risk of overfitting (Hadlock Pierce, 2010) [38]. The Whited-Wu (WW) index (Whited Wu, 2006)[39] partly alleviates multicollinearity concerns, yet it relies on numerous financial variables, making the measurement process relatively complex. By contrast, the SA index proposed by Hadlock & Pierce, (2010) [38], which uses firm size and firm age as core variables, offers both simplicity and robustness, and has been widely applied in recent financing constraint studies (Yue Li, 2023[40]; Zhu, et al., 2023[41]). Based on this rationale, we adopt the SA index to measure the degree of corporate financing constraints. The calculation formula is as follows:

$$SA\ Index = -0.737 \times Size + 0.043 \times Size^2 - 0.040 \times Age$$

Where $Size_{i,t}$ denotes the natural logarithm of a firm's total assets, and $Age_{i,t}$ denotes firm age. To more intuitively capture the intensity of financing constraints, we employ the SA index, where smaller values indicate greater financing constraints.

The results are shown in Column (3) of Table 9. Green bond issuance (Green*Post) is positively correlated with the financing constraint (SA) at the 5% significance level, with an estimated

coefficient of 0.0534, indicating that green bond issuance can effectively alleviate financing constraints, thereby enhancing supply chain stability, verifying Hypothesis H2b of this paper.

Table 9. ESG Mediation Effect Test Results

Variables	(1) OLS	(2) Firm FE	(3) Two-way FE
Green*post	0.0275**	-0.0276***	0.0534***
	(0.0125)	(0.0066)	(0.0043)
ln(Asset)	0.0102	-0.1247***	0.0005
	(0.0065)	(0.0051)	(0.0042)
DebtRatio	-0.0006**	-0.0002	-0.0004***
	(0.0003)	(0.0002)	(0.0001)
TobinQ	0.0095***	0.0056***	0.0056***
	(0.0019)	(0.0007)	(0.0008)
Age	0.0021***	0.0050***	0.0008***
	(0.0003)	(0.0003)	(0.0002)
CurrentRatio	0.0090***	0.0045***	0.0021***
	(0.0012)	(0.0006)	(0.0004)
ROA	0.0416	0.1115***	-0.0214***
	(0.0350)	(0.0134)	(0.0063)
Model Specifications	None	Firm	Firm & Year
Fixed Effects			
Observations	26,107	25,762	25,762

Note: The standard error is indicated in parentheses. *, **, ***, indicate significance levels at 10%, 5% and 1%, respectively.

Furthermore, the alleviation of financing constraints enables enterprises to invest substantial funds in introducing advanced technology and equipment, formulating innovation incentive mechanisms, and building high-tech R&D teams. It can further promote the protection of intellectual property rights for scientific and technological achievements and their market transformation, thereby greatly enhancing the quality of product innovation (Wu, et al., 2024)[42], and promoting the quality improvement of supply and demand. In summary, improving corporate ESG performance can promote the quality improvement of supply and demand in the industrial chain and supply chain through the channel of alleviating financing constraints and reducing financing costs.

8. Conclusions

With the continuous improvement of the green financial system, green bonds, as a core tool connecting enterprises' green transformation and the capital market, have gradually highlighted their profound impact on supply chain governance. Based on data from Chinese A-share listed companies during 2013-2022, this study systematically explores the impact of green bond issuance on firms' supply chain concentration and its underlying mechanisms using multiple empirical methods, including the progressive difference-in-differences (DID) model, instrumental variable (IV) approach, and Propensity Score Matching-DID (PSM-DID). Heterogeneity analysis is also conducted by incorporating regional and industrial characteristics. The empirical findings are as follows:

(1) Green bond issuance significantly reduces supply chain concentration, and this conclusion remains robust after a series of robustness tests, such as instrumental variable verification, PSM-DID, placebo tests, and replacement of the dependent variable;

(2) Heterogeneity analysis reveals that the supply chain diversification effect of green bonds exhibits significant disparities: enterprises in eastern China achieve a more pronounced reduction in supply chain concentration through green bond issuance compared to those in central and western regions, and non-heavy-polluting industries outperform heavy-polluting industries in leveraging green bonds;

(3) Mechanism tests confirm that green bond issuance reduces supply chain concentration primarily through two channels: first, improving firms' ESG (Environmental, Social, and Governance) scores to alleviate information asymmetry between upstream and downstream supply chain partners and enhance cooperative trust; second, mitigating financing constraints to provide financial support and risk resistance capacity for supply chain diversification. These mechanisms align with the internal logic of signaling theory, stakeholder theory, and pecking order theory;

(4) The supply chain optimization effect of green bonds also depends on the external institutional environment and industrial attributes, with more pronounced effects observed in regions and industries featuring higher marketization levels and better foundations for green transformation.

This study has the following limitations: First, the sample size is relatively limited. The sample is only confined to Chinese A-share listed companies, failing to cover unlisted enterprises and small and medium-sized enterprises (SMEs), which may affect the generalizability of the research conclusions. Second, the classification of green bonds and the differentiation of capital investment directions are not refined. This study does not distinguish between different types of green bonds (e.g., green financial bonds, green corporate bonds) and their specific investment fields, making it unable to capture their heterogeneous impacts on supply chain concentration. Third, the discussion on policy synergy is insufficient. Green bonds interact with supporting policies such as green credit and green transformation subsidies in practice, but this study does not deeply analyze their interactive mechanism, leading to insufficient comprehensiveness of the proposed policy recommendations.

Future research can make up for the above deficiencies in the following more specific directions: First, expand the sample size and scope by incorporating unlisted enterprises, small and medium-sized enterprises (SMEs), and even enterprises in emerging green industries into the research sample, which will help enhance the generalizability of the conclusions and provide more targeted empirical evidence for different types of enterprises to apply green bonds. Second, refine the classification of green bonds (e.g., by issuer, issuance term) and systematically track the specific flow of bond funds, focusing on exploring the heterogeneous impacts of green bonds invested in different fields (such as clean energy, pollution control) on supply chain governance. Third, strengthen the research on policy synergy: on the one hand, introduce interaction terms into the empirical model to quantitatively test the synergistic or inhibitory effects between green bonds and supporting policies such as green credit and carbon emission trading policies; on the other hand, explore the optimal policy combination mode under different institutional environments and industry backgrounds to further improve the effectiveness of supply chain governance.

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