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Financing Broader Sustainable Transition: Green Finance Policies and Cross-Regional Green Innovation Spillovers Along Supply Chains

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ABSTRACT In the pursuit of sustainable development, whether green finance policies can transcend geographical boundaries and reshape resource allocation to generate cross-regional green innovation spillovers along supply chains deserves in-depth investigation. This study conducts an empirical analysis using a difference-in-differences (DID) approach. The results show that: (1) the establishment of green finance pilot zones in the regions where upstream supply chain firms are located significantly promotes green innovation among downstream firms outside the pilot zones, confirming the existence of a cross-regional spillover effect of green finance policies. (2) The establishment of green finance pilot zones significantly alleviates financing constraints for firms within the pilot zones. Supported by a "push-pull" theoretical framework, credit transmission among supply chain firms provides a channel for capital flows, enabling the incentive effects generated by green finance policies to spill over to downstream firms outside the pilot zones. (3) Further analysis reveals that the cross-regional green innovation spillover effect driven by positive corporate credit transmission is influenced by multiple factors at the firm, supply chain, and environmental levels. These findings not only provide theoretical insights into corporate green transformation but also offer empirical support for leveraging green finance policies to achieve broader sustainable development goals (SDGs).

Key words Green finance policies; Green finance pilot zone; Enterprise credit transmission; Green innovation spillover

1 Introduction

Against the backdrop of intensifying climate change, tightening ecological constraints, and the accelerating transition toward low-carbon development, how to direct financial resources toward green, low-carbon, and sustainable development sectors has become a central concern for both academia and policymakers worldwide(Steckel et al., 2017; Clark et al., 2018; Folqué et al., 2021). Whether under the emissions reduction commitments of the Paris Agreement or the continued emphasis of the Sustainable Development Goals (SDGs) on green growth, climate action, and responsible investment, it is increasingly recognized that green transition is not merely a matter of industrial restructuring and technological change, but also one of reshaping the logic of capital allocation and the architecture of financial support. In recent years, green finance has evolved from a supplementary tool of environmental governance into an important policy instrument for promoting the comprehensive sustainable transformation of economies and societies(Dikau and Volz, 2021; Shen et al., 2024; Jiang and Ma, 2025). Particularly for emerging and transition economies, how green finance policies can alleviate financing constraints on green projects, stimulate green innovation, and facilitate the implementation of sustainable development goals has become a research question of both theoretical and practical significance.

In this context, China provides a highly relevant setting for examining how financial mechanisms can support this transition. As one of the world's largest developing economies, China has recently accelerated the development of a financial support system tailored for green transformation(Wang, 2023). Within this process, the establishment of Green Finance Reform and Innovation Pilot Zones (hereafter "green finance pilot zones" or "pilot zones") represents a pivotal institutional experiment(Xu et al., 2023; Zhang et al., 2024). By integrating financial resources and fostering green innovation at the regional level, these pilot zones have reshaped local financial ecosystems(Sharma and Babic, 2025), improved funding access for green projects(Zhang, 2023), and created favorable conditions for corporate green innovation(Liu and Wang, 2023; Chang et al., 2024). Such explorations offer valuable global insights for other developing nations urgently seeking to mobilize green capital for their sustainable transitions.

Existing studies generally suggest that green finance policies can promote green innovation and green transformation among firms within policy-covered regions by improving access to finance, optimizing capital allocation, and strengthening environmental constraints(Yu et al., 2021; Liu and Li, 2025; Zou and Zhang, 2025).

However, the literature has largely assumed that policy effects are confined to the regions where the policy is implemented, and has paid limited attention to a further question: can green finance policies transcend geographical boundaries and generate cross-regional effects beyond policy-covered areas? This question is crucial for accurately assessing the actual effectiveness of green finance policies. If policy effects are not limited to pilot zones themselves but can diffuse outward through inter-firm economic linkages, identifying policy impacts solely from a territorial perspective may underestimate their overall scope and fail to uncover the transmission mechanisms operating within broader production networks.

In practice, firms do not exist in isolation but are deeply embedded in supply chain networks(Govindan et al., 2020). Relationships between upstream and downstream firms involve not only stable product transactions, but also the transmission of capital, credit, and risk along the chain(Lin and Pan, 2023). Especially when formal financing channels such as bank credit, bond financing, and equity financing are subject to high institutional thresholds and prudent regulatory constraints, inter-firm credit, serving as the most flexible capital transmission channel with the lowest transaction costs within the supply chain, can partially function as a supplementary financing mechanism and a quasi-financial intermediary linking upstream and downstream firms(Andrieu et al., 2018; Zheng et al., 2025). For firms located outside the pilot zones, direct access to the credit support and financing convenience associated with green finance policies may be limited. However, if their upstream partners are located within green finance pilot zones and thereby benefit from more favorable financing conditions, an important question arises: can these financial advantages be transmitted along the supply chain and subsequently translated into enhanced green innovation among downstream firms? Accordingly, this paper shifts the analytical focus of green finance policy research from “within-region effects” to “cross-regional spillover effects via supply chains,” paying particular attention to whether green finance policy effects can break through geographical boundaries along the credit ties between suppliers and customers.

To fully uncover the micro-mechanisms behind this spillover process, this study draws on Resource Dependence Theory (RDT) and Signaling Theory (ST) to construct a "push-pull" theoretical framework. This framework aims to clarify two critical theoretical links: first, the endogenous motivation for profit-driven upstream firms to voluntarily share financial benefits with downstream partners via inter-firm credit; and second, the underlying logic that compels downstream firms, upon receiving highly fungible funds, to specifically allocate them toward green innovation rather than general capacity expansion. We posit that this cross-regional spillover is jointly driven

by an RDT - based "push" and an ST - based "pull" (Hillman et al., 2009; Connelly et al., 2011).Specifically, the "push" mechanism occurs as upstream firms supply credit downstream to stabilize the supply chain networks upon which their survival depends, while the "pull" mechanism emerges when downstream firms actively invest in green innovation to signal sustainable compliance and secure long-term cooperation.

Compared with the existing literature, this study makes four main contributions. First, prior studies have mainly focused on the direct effects of green finance policies on firms within pilot regions, with limited discussion of whether such policy effects can extend beyond territorial boundaries. By situating firms within supply chain networks, this paper broadens the research boundary of the innovation effects of green finance policies and shows that such effects may spill over beyond policy-covered regions through upstream–downstream linkages. Second, although previous studies have recognized the importance of inter-firm credit in policy transmission, how it connects upstream policy beneficiaries with downstream innovation responses remains underexplored in the context of green finance policy. By focusing on the relaxation of financing constraints and the transmission of credit among firms, this paper opens the “black box” of the mechanism underlying the cross-regional innovation spillover of green finance policies. Third, by combining Resource Dependence Theory (RDT) and Signaling Theory (ST), this study constructs a novel "push-pull" framework to explain two key issues: why upstream firms actively share policy dividends, and why downstream firms are willing to invest these funds into green innovation. Fourth, whereas existing studies on heterogeneity have largely focused on firm-level characteristics, this paper further examines heterogeneity from three dimensions—firm characteristics, supply chain characteristics, and external environmental conditions—thereby providing a more layered perspective for understanding the boundaries and contingent effects of policy-driven financial incentives.

Overall, this study seeks to demonstrate that the effects of green finance policies are not necessarily confined to their regions of implementation but can diffuse across geographical boundaries through supply chain networks. Identifying this spillover effect not only contributes to a more comprehensive evaluation of green finance policy effectiveness but also provides novel empirical evidence and policy insights for leveraging supply chain coordination to achieve broader sustainable development goals (SDGs).

2 Literature review and theoretical analysis

2.1 Literature review

2.1.1 Effects of green finance policies

Green finance is widely regarded as an important institutional arrangement through which finance supports sustainable development. Its core purpose is to guide the coordinated development of economic growth, resource use, and environmental protection through financial resource allocation and policy incentives(Wang et al., 2022; Ye and Tian, 2025). With the continuous improvement of green finance policy system, the literature has gradually shifted from early discussions of the conceptual connotations, institutional attributes, and developmental logic of green finance toward empirical identification of policy effects. Overall, existing studies suggest that green finance policies have become an important policy instrument for promoting regional green development and corporate green transformation(Hua et al., 2024; Wang et al., 2024).

From the perspective of research scope, the existing literature mainly examines the effects of green finance policies at the macro and micro levels. At the macro level, studies have focused on the impacts of green finance policies on regional green economic efficiency, pollution control, energy structure optimization, and the coordinated effects of pollution reduction and carbon mitigation(D'Orazio and Popoyan, 2019; Liu et al., 2023; Zhang et al., 2024; Meng et al., 2025). Most of these studies support the view that green finance policies significantly improve regional green development performance. At the micro level, related research has further investigated the effects of green finance policies on corporate green transformation, corporate social responsibility, environmental information disclosure, and total factor productivity(Sadiq et al., 2022; Berikhanovna et al., 2023; Zhou et al., 2023; Zhang et al., 2026). These studies generally show that such policies improve firms' resource allocation conditions and generate positive incentives for sustainability-oriented corporate behavior. At the same time, whether green finance policies can stimulate green technological innovation has become a major concern in recent years. Most existing studies confirm that green finance policies promote corporate green innovation by easing financing constraints, strengthening expectations of environmental regulation, and improving the incentive structure for innovation(Irfan et al., 2022; Ahmed et al., 2024; Lei et al., 2025).

Importantly, however, the literature also suggests that green finance policies do not generate homogeneous effects across firms. Unlike traditional financial policies, which tend to emphasize broad coverage and general inclusiveness, green finance policies are typically more targeted and selective(Arif et al., 2021). Their incentive effects vary with firms' pollution attributes, industry characteristics, and existing green development

conditions(Criscuolo and Menon, 2015; Pan and Lin, 2024). In other words, the boundaries of green finance policy effects are not fixed, but depend jointly on firm heterogeneity and the degree of policy fit. Even so, most existing studies still identify policy effects primarily within policy-covered areas or among firms directly exposed to policy treatment, while paying relatively limited attention to whether such effects may extend beyond administrative boundaries through inter-firm economic linkages.

In this sense, although the existing literature has provided substantial evidence on the direct effects of green finance policies at the regional and firm levels, it has not systematically examined whether these policies may generate cross-regional innovation spillovers from "points" to "chains" through supply chain networks. Given that firms are deeply embedded in supply chains, and that green finance policies may be transmitted downstream through improved upstream financing conditions, resource reallocation, and credit support, a purely place-based understanding of policy effects may underestimate the actual scope of green finance policy influence. Against this background, this study extends the research boundary of green finance policy effects from regions and individual firms to supply chain networks, with a particular focus on whether policy-driven green financial incentives spill over to firms outside pilot zones and generate cross-regional green innovation effects.

2.1.2 Inter-firm credit and the transmission of policy effects

To understand why green finance policies may transcend geographical boundaries and diffuse through supply chains, the transmission role of inter-firm credit deserves particular attention. As an important component of supply chain finance, inter-firm credit not only helps relieve short-term financial pressure on firms, but also partly compensates for the limitations of formal financial systems in serving chain-based inter-organizational relationships(Demirgüç-Kunt and Maksimovic, 2002; Fisman and Love, 2003; Hyndman and Serio, 2010). This is especially relevant in contexts where formal financing channels—such as bank lending, bond financing, and equity financing—are constrained by institutional thresholds, approval requirements, and prudent regulation(Hoff and Stiglitz, 1990; Nguyen and Canh, 2021). Under such conditions, credit arrangements formed through trading relationships often become an important channel linking upstream and downstream firms.

Earlier studies mainly focused on the substitutive relationship between inter-firm credit and bank credit, arguing that when firms cannot obtain sufficient financing from the formal financial system, inter-firm credit can serve as an important supplementary source and help ease financing constraints(Atanasova, 2007; Fabbri and Klapper, 2016).

In recent years, as inter-firm credit has become increasingly important within supply chain networks, a growing body of literature has begun to regard it as a key intermediary mechanism in the transmission of policy effects, and has further explored the chain-like diffusion and spillover effects it may generate(Al-Hadi and Al-Abri, 2022; Lin and Pan, 2023). Related studies show that some regional or pilot policies do not remain confined to directly covered entities, but can diffuse to firms not directly covered by the policy through trade credit networks, capital chain relationships, and upstream–downstream transactional connection, thereby affecting exports, investment, employment, and other aspects of firm behavior(Costello, 2020; Barrot and Nanda, 2020).

However, the existing literature on the policy transmission effects of inter-firm credit has focused primarily on policy areas such as trade facilitation and the integration of technology and finance(Costello, 2020; Zhou and Li, 2023; Liu et al., 2025). Whether inter-firm credit similarly serves as an important channel of cross-regional policy transmission in the context of green finance policy remains insufficiently discussed. This question is particularly important in the case of green finance pilot zones, which are spatially targeted policy experiments. When upstream firms benefit from policy incentives and experience relaxed financing constraints, whether they transmit part of these financial advantages to downstream partner firms through inter-firm credit, and whether this in turn promotes green innovation among firms outside pilot zones, remains a key issue to be identified.

Accordingly, building on the literature on inter-firm credit transmission, this study extends the analysis of policy transmission mechanisms to the field of green finance. It focuses on how inter-firm credit connects “upstream policy beneficiaries” with “downstream innovation responders” and examines its role in the cross-regional spillover effects of green finance policies. By incorporating inter-firm credit into the analytical framework linking green finance policy, supply chain relationships, and green innovation, this study seeks to reveal how policy-driven green financial incentives achieve cross-regional diffusion through credit transmission within supply chains, thereby providing a mechanism-based explanation for the actual boundaries of green finance policy effects.

2.2 Theoretical analysis and research hypotheses

The potential impact of green financial policies on enterprises' green innovation mainly lies in their ability to change the financing conditions of green investment through institutional arrangements, thereby reshaping the expected returns of green innovation activities(Yu et al., 2021). Compared with general technological innovation, green

research and development and green upgrading usually require high upfront investment, long return cycles, and considerable uncertainty(Berrone et al., 2013). Therefore, under the conventional loan framework, such activities are more likely to encounter problems such as insufficient credit support, higher borrowing costs, and mismatched terms(Campiglio, 2016). In this case, the incentive measures brought by green financial policies, such as green loans, green bonds, interest subsidies, and credit enhancement mechanisms, can provide more targeted financial support for green projects, help alleviate the financing constraints related to green innovation, and enhance the ability of enterprises to continuously invest in green research and development and technological upgrading.

Beyond easing financing constraints, green finance policies also have a clear guiding function. The allocation of financial resources is not neutral, but is often linked to firms' environmental performance, green qualifications, emissions reduction outcomes, and disclosure practices. In order to obtain continued policy support and financing advantages, firms have incentives to make observable and verifiable improvements in green technologies, cleaner production processes, and green products(Connelly et al., 2011). This incentive-and-discipline mechanism may not only encourage firms to increase green innovation input, but also help them build green reputation and longer-term competitive advantages in the market.

More importantly, the effects of green finance policies may not be confined to the regions in which they are implemented. When firms are embedded in relatively stable supply chain networks, upstream and downstream firms are connected not only through product transactions, but also through credit linkages, capital flows, and risk sharing(Gelsomino et al., 2016). Even when downstream firms are not directly covered by the policy, improvements in the financing capacity, creditworthiness, and liquidity position of upstream firms induced by policy-driven financial incentives may still be transmitted downstream through trade credit relationships in the supply chain. As a result, policy effects may extend beyond regional boundaries and generate spillover effects on green innovation among firms located outside the pilot zones. Based on this reasoning, this study proposes the following hypothesis:

H1. The establishment of green finance pilot zones in the regions where upstream supply chain firms are located significantly promotes green innovation among downstream firms outside the pilot zones.

A necessary condition for such spillovers is that green finance policies first improve the financing conditions of firms located within the policy-covered regions. As

discussed above, through institutional innovation and the optimization of financial instruments, green finance pilot zones have, to some extent, reduced financing barriers and increased access to capital for green projects. On the one hand, the establishment of pilot zones encourages financial institutions to improve mechanisms related to green credit, green bonds, and environmental risk assessment, making it easier for green projects to obtain targeted financial support(Zhang, 2023). On the other hand, as systems such as green ratings, environmental information disclosure, and green certification continue to improve, the identifiability and verifiability of green assets are enhanced, which strengthens the credit foundation and market recognition of green projects and creates more favorable conditions for firms to obtain bank loans and bond financing(Eliwa et al., 2021).

It is worth noting that green finance policies do not provide indiscriminate support to all firms or projects. Instead, such support is generally conditional on the identification of green attributes and compliance requirements. In most cases, firms or projects must satisfy specific criteria related to environmental performance, emissions reduction, or green certification in order to obtain preferential credit, financing support, and access to relevant financial products(Su and Lian, 2018). Therefore, the financing improvements brought about by such policies are unlikely to be evenly distributed across firms, and may instead vary according to firms' pollution attributes, governance capacity, and green credentials. Compared with heavily polluting firms, non-heavily polluting firms are generally more likely to satisfy the eligibility and identification criteria of green finance and thus more likely to benefit from policy support(Xu and Li, 2020). By contrast, heavily polluting firms, which often face greater environmental compliance pressure and weaker green attributes, may not benefit from such incentives to the same extent, and the easing of their financing constraints may be limited. Accordingly, this study proposes the following hypotheses:

H2a. The establishment of green finance pilot zones effectively alleviates financing constraints for non-heavily polluting firms within the pilot zones.

H2b. The establishment of green finance pilot zones has no significant effect in alleviating financing constraints for heavily polluting firms within the pilot zones.

However, to understand how the improvement of upstream green financing conditions specifically translates into downstream green innovation responses, two micro-mechanisms behind this spillover process must be clarified. First, why would profit-driven upstream firms, when receiving more financial support due to green finance policies, have the motivation to "share" green credit dividends with downstream

partners in the form of trade credit rather than solely serving their own operations? Second, since inter-firm credit (trade credit) is a highly fungible financial resource, what ensures that it flow into green R&D rather than general production expansion? To bridge this gap, this study constructs a "push-pull" theoretical framework based on Resource Dependence Theory (RDT) and Signaling Theory (ST).

From the perspective of Resource Dependence Theory (the "push" mechanism), upstream firms in pilot zones are not isolated beneficiaries but are embedded in a deep network of interdependence with their downstream customers (Hillman et al., 2009). To maintain customer relationships, preserve supply chain stability, promote chain-wide coordination, and lock in long-term market demand, upstream firms have the motivation to provide more trade credit support to downstream partners facing green transition cost pressures—by extending payment periods, allowing delayed settlement, or relaxing credit terms(Ersahin et al., 2024). Furthermore, stakeholder pressure reinforces this "push": since pilot-zone firms face stricter green compliance regulation, they must ensure the environmental integrity of the entire supply chain to safeguard their own policy-driven financial advantages(Sarkis et al., 2011). Therefore, providing trade credit becomes a strategic tool for upstream firms to "push" downstream partners toward sustainable development.

Simultaneously, Signaling Theory (the "pull" mechanism) explains why downstream firms invest these resources in green innovation(Connelly et al., 2011). In the context of green transition, general production expansion is a "cheap signal" that fails to prove a firm’s long-term viability . In contrast, investing in green innovation is a "costly signal" that can reliably convey a firm's strategic alignment with national green policies and its superior governance capacity. By investing the received trade credit in green R&D and cleaner production, downstream firms send a strong "quality and compliance" signal to their upstream partners(May et al., 2007). This "pull" effectively attracts sustained credit support and solidifies their position in the green supply chain.

In summary, inter-firm credit relationships may become an important channel for green finance policies to spread across regions and may also influence the intensity of policy spillover effects. The stronger the credit support transmitted from upstream to downstream firms, the more likely policy effects will cross regional boundaries and translate into higher levels of green innovation among downstream firms. Accordingly, this study proposes the following hypotheses:

H3a. Inter-firm credit plays a transmission role in the effect of green finance policies on green innovation among downstream firms outside the pilot zones.

H3b. The stronger the intensity of inter-firm credit transmission, the stronger the spillover effect of policy-driven financial incentives on downstream non-pilot firms along the supply chain.

Based on the theoretical analysis and research hypotheses presented above, this study constructs a "push-pull" theoretical framework for the cross-regional green innovation spillover of green finance policies via supply chains. The logical relationships and specific transmission pathways are illustrated in Figure 1.

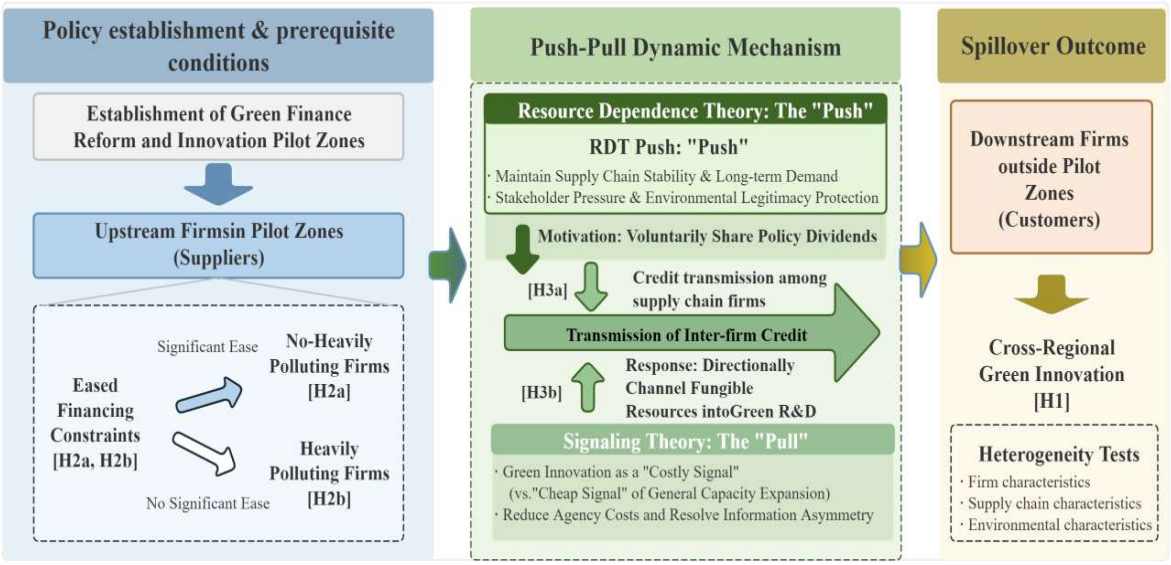


Figure 1
Mechanism Framework Diagram.

3 Research Design

3.1 Model construction

To investigate whether green finance policies can promote green innovation among downstream firms located outside the pilot zones, the treatment group and the control group are divided according to whether green finance pilot zones have been established in the regions where the top five suppliers of downstream non-pilot firms are located. The treatment group must satisfy the following conditions: ① the downstream firm is located in a region where no green finance pilot zone has been established; ② after year t, one or more of the top five suppliers of the downstream non-pilot firm are located in regions where green finance pilot zones have been established. Based on this, the following econometric regression model is constructed:

$$lnCGI_{ict}=\alpha_0+\alpha_1\times Shock_{it}+\sum Controls+\mu_{ct}+\lambda_i+\varepsilon_{ict} \quad (1)$$

Among these variables, the subscript i denotes the downstream non-pilot firm in the supply chain, while c and t represent region and year, respectively. $lnCGI_{ict}$ is the green innovation variable of firm i in year t; $Shock_{it}$ is a dummy variable indicating whether the regions where the top five suppliers of firm i are located established green finance pilot zones in year t; $Controls$ refers to the selected control variables; μ_{ct} and λ_i denote city-year fixed effects and firm fixed effects, respectively; and ε_{ict} represents the random disturbance term. α_1 captures the "net effect" that this study focuses on. If the coefficient α_1 is significantly positive, it confirms that green finance policies can promote cross-regional green innovation spillovers to downstream firms along the supply chain.

3.2 Variable selection

(1) Green finance policy dummy variable (Shock). To capture the green finance policy shock faced by downstream firms through supply chain transmission, this study treats the "establishment of Green Finance Reform and Innovation Pilot Zones" as an exogenous institutional shock at the regional level. Specifically, the dummy variable $Shock_{it}$ is constructed based on whether green finance pilot zones have been established in the regions where the top five suppliers of downstream firms are located. Considering that the support targets of green finance policies do not unconditionally cover all firms or projects, and in line with the research hypotheses and the interpretation of the regression results, samples in which the suppliers are heavily polluting firms are excluded. $Shock_{it}$ = 1 indicates that the regions where the top five suppliers of firm i are located established pilot zones in year t; $Shock_{it}$ = 0 indicates that the regions where the top five suppliers of firm i are located had not established pilot zones in year t.

(2) Corporate green innovation (lnCGI). Following existing literature, green patents are widely regarded as a reliable and objective proxy for evaluating a firm's green technological advancement(Feng et al., 2024). Because the WIPO green technology classification (IPC codes) exclusively applies to invention and utility model patents in the Chinese patent system (Qi et al., 2018), the total number of green patents effectively comprises these two categories. Therefore, to comprehensively capture the overall output and active engagement of firms in their green transition, corporate green innovation is measured as the natural logarithm of one plus the sum of granted green invention patents and granted green utility model patents.

(3) Control variables. This study includes control variables capturing firm characteristics at both the financial and managerial levels(Amore and Bennedsen, 2016).

Financial-level variables include firm size (Size), measured as the natural logarithm of total assets; leverage (Lev), measured as the ratio of total liabilities to total assets at year-end; profitability (Roa), measured as the ratio of net profit to average total assets; and growth capacity (Growth), measured by the growth rate of operating revenue. Managerial-level variables include CEO duality (Dual), measured as a dummy variable indicating whether the chairman of the board and the general manager are the same person; and Tobin's Q (TobinQ), measured as the ratio of the sum of the market value of tradable shares, the net asset value of non-tradable shares, and the book value of liabilities to total assets.

3.3 Data source

The initial sample consists of Chinese A-share listed companies on the Shanghai and Shenzhen stock exchanges from 2012 to 2022. The core data include supplier–customer relationship data, financial data, and patent data disclosed by listed companies, which are obtained from the CSMAR database, the CNRDS database, annual reports of listed companies, statistical yearbooks, and other sources. Based on the merged dataset, this study excludes firms with abnormal operating status, such as PT, ST, and *ST firms; firms in the financial and insurance industries; firms with incomplete supplier information during the sample period; suppliers that are not corporate entities; and firms that experienced significant changes in their supplier lists before and after the policy implementation. All continuous variables are winsorized at the 1% and 99% levels. The final sample consists of 6,079 firm-year observations from 663 firms.

4 Empirical results

4.1 Baseline regression results

The regression results on the spillover effect of green finance policies on green innovation among downstream firms in the supply chain are reported in Table 1. Column (1) presents the results without control variables, and the coefficient on lnCGI is significantly positive at the 5% level. Column (2) reports the results after adding control variables, and the coefficient remains significantly positive at the 5% level, with a value of 0.048. This indicates that the establishment of green finance pilot zones in the regions where upstream firms are located significantly improves the level of green innovation among downstream firms outside the pilot zones, confirming the cross-regional spillover effect of green finance policies through the supply chain. Therefore, H1 is supported.

Table 1

Baseline regression results.

	lnCGI	
Variables	**(1)**	**(2)**
Shock	0.049**	0.048**
	(2.26)	(2.27)
Control variables	NO	YES
Fixed effect	YES	YES
N	6,079	6,079
Adj.R-squared	0.826	0.828

Notes:***, **, * indicate statistical significance at $p < 0.01$, $p < 0.05$, and $p < 0.10$ respectively; the values in parentheses are the t-values, and the same applies below.

4.2 Identification condition test and robustness test

4.2.1 Regional selection randomness test - Geographical characteristic factors

Although no explicit criteria were set for the geographical selection of pilot zones, the relevant policy plans still reflected considerations regarding local development foundations and future development prospects. Therefore, geographical characteristics are likely to be important factors in determining whether a region is approved for the establishment of a green finance pilot zone. On this basis, while including city-year fixed effects in the baseline regression, this study further employs a logit model to identify the characteristics that may affect the approval of green finance pilot zones. The results show that regional GDP, the level of commercial development, industrial structure, and the level of green development are all significantly positively correlated with the establishment of pilot zones. The interaction terms between the baseline values of these geographical characteristics and the time dummy variables are then added to the baseline model. As reported in column (1) of Table 2, the results continue to support the findings of the baseline regression.

4.2.2 Time set randomness test - expected effect

Because policy introduction is not random over time and is mainly driven by internal forces such as environmental governance pressure, economic transformation needs, and the growth of green investment, this study follows Lu et al. (2021) to test whether the establishment of green finance pilot zones exhibits anticipatory effects. Specifically, one, two, and three periods prior to the actual policy implementation are respectively treated as fictitious policy timing dummy variables, and the sample before the actual policy implementation is re-estimated. The results are reported in columns (2)–(4) of Table 2. None of the estimated coefficients is significant, indicating that the pilot zones

do not generate anticipatory effects on firms outside the pilot areas, and that the timing of policy establishment satisfies the randomness assumption.

Table 2
Randomness test results for regional selection and time setting.

	lnCGI			
	Regional selection randomness test	Time set randomness test		
Variables	（1）	（2）	（3）	（4）
Shock	0.107** (2.28)			
Shock (pretime1)		0.026 (1.10)		
Shock (pretime2)			-0.005 (-0.28)	
Shock (pretime3)				-0.004 (-0.26)
Geographical characteristics×time dummy variables	YES	NO	NO	NO
Control variables	YES	YES	YES	YES
Fixed effect	YES	YES	YES	YES
N	5,291	2,643	2,643	2,643
Adj.R-squared	0.827	0.912	0.912	0.912

4.2.3 Parallel trend test

The parallel trend assumption in this study requires that, prior to the establishment of green finance pilot zones, there be no systematic difference in the trend of green innovation between the treatment group and the control group. To verify this assumption, the following regression model is constructed:

$$lnCGI_{ict}=\alpha_0+\sum_{k=-3}^{3}\alpha_k\times Shock_{it_{0+k}}+\sum Controls+\mu_{ct}+\lambda_i+\varepsilon_{ict} \qquad (2)$$

Here, t_0 denotes the year in which green finance pilot zones began to be established, and t_{0+k} denotes the kth year before or after policy implementation. α_k is the regression coefficient within the policy event window, while the meanings of the remaining variables are basically the same as those in the baseline empirical model. Years more than three periods before or after the policy shock (k<−3 or k>3) are grouped into the third year before or after the shock (i.e., year −3 or year 3), and the period immediately preceding the policy shock is taken as the reference group. In addition, following Beck et al. (2010) , the pre-treatment mean is first calculated, and

the regression coefficients and confidence intervals for all periods are then demeaned to address potential pre-trends as much as possible.

Figure 2 presents the estimated values of α_k with 95% confidence intervals. The results show that, before the implementation of the pilot policy, the confidence intervals of α_k fluctuate around zero and the estimated coefficients are all insignificant, indicating that there is no significant difference in the level of green innovation between the treatment group and the control group. Thus, the model passes the parallel trend test. In addition, after the policy shock, α_k becomes significantly positive, suggesting that the establishment of green finance pilot zones in the regions where upstream firms are located significantly improves green innovation among downstream firms outside the pilot zones along the supply chain.

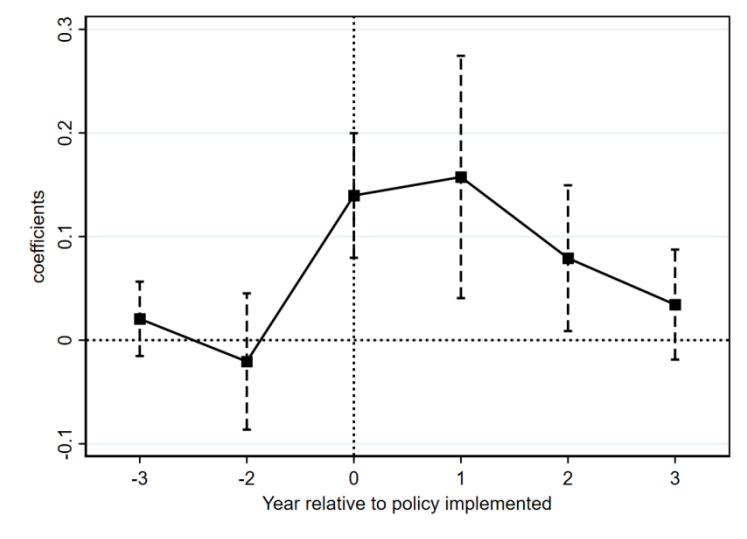


Figure 2
Parallel trend test.

4.2.4 Placebo test

The above results may simply reflect natural time trends or be driven by random factors. To address this concern, this study conducts a placebo test by randomly constructing the green finance pilot zone policy indicator. After 500 rounds of random sampling and regression estimation, the results, shown in Figure 3, indicate that the estimated coefficients are normally distributed around zero and located to the left of the true coefficient. This suggests that the observed policy effect is not driven by random factors, and that green finance policies significantly promote green innovation among downstream firms outside the pilot zones along the supply chain.

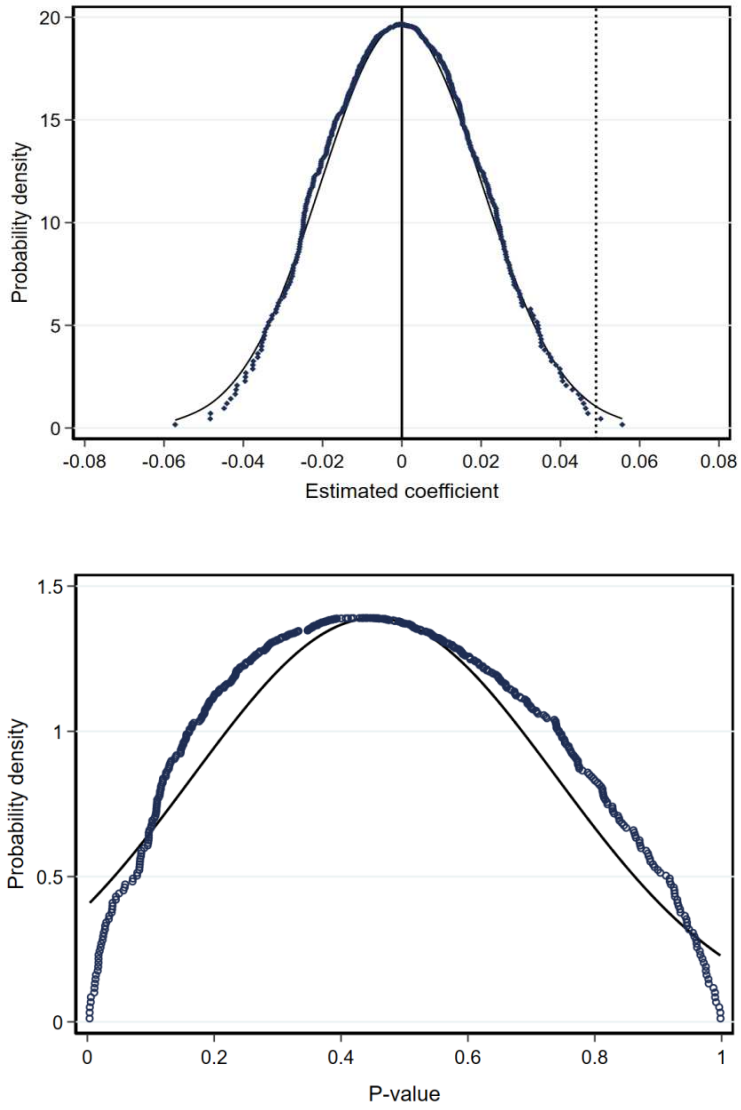


Figure 3
Placebo test.

4.2.5 Other robustness tests

To further examine the robustness of the regression results, this study adopts several additional strategies.The results are reported in columns (1)–(3) of Table 3. (1) Excluding interference from other policies. To more accurately identify the net spillover effect of green finance policies on innovation and to avoid potential interference from other contemporaneous policies, this study controls for two key policy initiatives. The first is the Green Credit Guidelines issued by the China Banking Regulatory Commission in 2012, which aimed to optimize the green credit structure, encourage banking institutions to increase support for the green economy, low-carbon economy, and circular economy, and prevent environmental and social risks. The second is the carbon emissions trading pilot launched in 2013, which was intended to

strengthen environmental regulation and induce corporate green innovation. To rule out interference from these policies, dummy variables for both policies are included in the baseline model, and the regression results remain robust. (2) Changing the clustering level. In the baseline regression, standard errors are clustered at the firm level. However, since firms located in different regions may also be correlated with one another, the standard errors are further clustered at the regional level to re-estimate the model, and the results remain robust. (3) Including industry fixed effects. To further eliminate potential industry-level confounding factors and make the estimation more focused on the core effect of interest, industry fixed effects are added in addition to city-year fixed effects and firm fixed effects. The regression results remain robust.

Table 3
Other robustness tests.

	Exclude other policy interference	**Changing the clustering level**	**Including industry fixed effects**
Variables	**(1)**	**(2)**	**(3)**
Shock	0.0479** (2.27)	0.048* (1.86)	0.046** (2.19)
the Green Credit Guidelines	YES	NO	NO
the carbon emissions trading pilot	YES	NO	NO
Control variables	YES	YES	YES
Industry FE	NO	NO	YES
City-year FE & Firm FE	YES	YES	YES
N	6,079	6,079	6,079
Adj.R-squared	0.828	0.828	0.829

4.3 Preliminary Analysis and Test of the Inter-firm Credit Transmission Effect

Based on the preceding theoretical and empirical analysis, the effects of green finance policies can be transmitted downstream along the supply chain, thereby generating cross-regional spillovers in green innovation. A key prerequisite for this process is that the policy first changes the financial conditions of firms within the pilot zones, ensuring that upstream firms benefit from the policy shock and obtain sufficient financial support. Specifically, the establishment of green finance pilot zones may provide financial support to firms through tax incentives, fiscal subsidies, or the provision of green bonds and green credit products, thereby alleviating the financing constraints faced by upstream firms(Ersahin et al., 2024). It is worth noting that green finance policies do not provide unconditional support to all firms or projects(Pan and Lin, 2024). Rather,

firms or projects must meet specific green development requirements in order to ensure that financial resources are directed toward areas consistent with sustainable development goals. Therefore, this study takes industry pollution intensity into account and separately evaluates the policy effects on firms in industries with different levels of pollution. The following model is constructed for empirical testing:

$$X_{qjct}=\alpha_0+\alpha_1\times Treat_c\times Post_t+\mu_{ct}+\lambda_q+\varepsilon_{qjct} \quad (3)$$

Here, X_{qjct} is the dependent variable representing the financing constraints of upstream pilot-zone firms in the supply chain, where subscript q denotes the firm (either a heavily polluting firm or a non-heavily polluting firm), j denotes industry, c denotes region, and t denotes year; $Treat_c$ and $Post_t$ are the dummy variables for the pilot region and the post-policy period, respectively. The regression results are reported in columns (1) and (2) of Table 4. Column (1) uses the sample of non-heavily polluting firms, and the coefficient on the interaction term is significantly negative at the 1% level. Column (2) uses the sample of heavily polluting firms, and the coefficient on the interaction term is not significant. These results indicate that the establishment of green finance pilot zones can effectively alleviate the financing constraints of non-heavily polluting firms within the pilot zones, but has no incentive effect on heavily polluting firms. Therefore, H2a and H2b are supported.

The above results confirm that green finance policies bring financing convenience to non-heavily polluting firms within the pilot zones, effectively alleviating the financing constraints faced by some firms. When upstream firms in the supply chain have sufficient funds, they have both the ability and the incentive to reallocate capital from the perspective of the supply chain as a whole, and to provide inter-firm credit to downstream firms by reducing the proportion of customer prepayments, extending payment periods, and increasing the proportion of accounts payable, thereby enhancing supply chain resilience and maximizing value (Costello, 2020). On this basis, this study further examines the effect of inter-firm credit transmission on the cross-regional spillover effect of green finance policies, and constructs a Intensity DID model for empirical testing:

$$lnCGI_{ict}=\alpha_0+\alpha_1\times Shock_{it}\times CI_i+\sum Controls+\mu_{ct}+\lambda_i+\varepsilon_{ict} \quad (4)$$

Here, CI_i denotes the intensity of inter-firm credit transmission. To avoid potential endogeneity arising from post-policy behavioral adjustments that may affect the intensity measure, and to smooth single-period fluctuations and measurement errors,

this study uses the average intensity of inter-firm credit transmission of firm i over the three periods prior to the establishment of green finance pilot zones as a proxy variable. The measurement of inter-firm credit intensity follows the related study by Wu et al. (2014) , which argues that accounts payable, notes payable, and advances from customers can all be used to measure a firm's ability to occupy upstream and downstream funds in the supply chain at "zero cost" or "low cost." The calculation is as follows:

$$CI_i = (Accounts\ Payable_{i,t+1} + Notes\ Payable_{i,t+1} + Customer\ Advances_{i,t+1}) / Year\text{-}end\ Total\ Assets_{it}$$

The regression results are reported in columns (2)–(3) of Table 4. Column (2) presents the results without control variables, while column (3) reports the results with control variables included. The coefficients on the interaction terms are all significantly positive at the 5% level. This indicates that inter-firm credit transmission links upstream suppliers and downstream customers within the supply chain. The stronger the intensity of inter-firm credit transmission, the stronger the spillover effect of green finance policies on downstream firms outside the pilot zones. Therefore, H3a and H3b are supported.

Table 4

Preliminary Analysis and Test of the Inter-firm Credit Transmission Effect.

	Preliminary Analysis: Financing constraints of upstream firms in pilot zones		**Transmission effect: Green innovation of downstream non-pilot firms**	
Variables	**（1）**	**（2）**	**（3）**	**（4）**
Treat×Post	-0.004***	0.000		
	(-2.67)	(0.05)		
Shock×CI			0.282**	0.270**
			(2.48)	(2.38)
Control variables	YES	YES	NO	YES
Fixed effect	YES	YES	YES	YES
N	11,973	5,280	6,079	6,079
Adj.R-squared	0.889	0.886	0.826	0.828

4.4 Further Analysis: Heterogeneity Tests

4.4.1 Firm characteristics: firm size and information disclosure quality

Downstream firms in the supply chain may exhibit heterogeneous responses to the cross-regional spillover effects of green finance policies transmitted through inter-firm credit, owing to differences in firm size and information disclosure quality(Garcia-Appendini and Montoriol-Garriga, 2013). On the one hand, compared with large firms,

small and medium-sized firms are more likely to be in a disadvantaged position in the financial system because of insufficient internal funds and lower creditworthiness, and therefore face more severe credit constraints in the financing process. Accordingly, following the Statistical Classification of Large, Medium, Small and Micro Enterprises (2017) issued by the National Bureau of Statistics of China, this study divides the sample into small and medium-sized firms and large firms based on operating revenue and conducts subgroup regressions. The results, reported in columns (1) and (2) of Table 5, show that when the effects of green finance policies are transmitted to downstream non-pilot firms through inter-firm credit, the coefficient is significantly positive at the 5% level for large firms, but insignificant for small and medium-sized firms. This suggests that, when policy shocks are transmitted through credit, large firms are more likely to benefit from the incentives generated by green finance policies affecting upstream firms in the supply chain, thereby improving their green innovation. By contrast, small and medium-sized firms are more likely to suffer from financial exclusion and credit discrimination within the financial system, which seriously constrains their access to the funds needed for production, operation, and development.

On the other hand, firms with lower external information disclosure quality typically confront severe information asymmetry and rigid financing constraints within formal financial markets, such as the banking sector. Consequently, compared to their more transparent counterparts, these opaque firms exhibit a much stronger reliance on informal financing channels embedded within the supply chain, particularly inter-firm credit. Accordingly, downstream firms are divided into two groups based on whether their KV index is above the annual industry mean, and separate regressions are conducted. The KV index mainly measures the degree of corporate information disclosure based on the dependence of investors' stock returns on trading volume. The calculation is as follows:

$$ln\left|\frac{P_t-P_{t-1}}{P_{t-1}}\right|=\lambda_0+\lambda\left(\frac{Vol_t}{Vol_0}-1\right)+\varepsilon$$

$$KV=\lambda\times10^6$$

Here, P_t denotes the closing price on day t, Vol_t denotes the trading volume (in shares) on day t, and Vol_0 denotes the average daily trading volume over all trading days within the estimation window. The KV index is constructed based on the λ coefficient obtained by running an ordinary least squares regression for each listed firm, while cases in which λ is negative are excluded. A smaller λ indicates more adequate information disclosure; accordingly, a higher KV value represents lower information disclosure quality. The regression results are reported in columns (3) and (4) of Table

5. For firms with high information disclosure quality, the coefficient on the interaction term is significantly positive at the 10% level, while for firms with low information disclosure quality, the coefficient is significantly positive at the 1% level. This suggests that, in contrast to formal financial institutions that rely heavily on standardized public information, inter-firm credit operates as an informal financing arrangement built upon long-term transactional trust. Downstream firms with lower public information disclosure quality typically confront severe financial friction and credit rationing within the traditional banking system. Consequently, they exhibit a significantly higher reliance on informal credit channels embedded within the supply chain. This aligns perfectly with the Signaling Theory (ST) "pull" mechanism discussed earlier: precisely because these firms are opaque to the external market, they possess a stronger marginal incentive to channel newly acquired supply chain funds into verifiable green innovation.

4.4.2 Supply chain characteristics: supply chain concentration and supply chain persistence

If downstream firms in the supply chain remain highly dependent on only a few upstream suppliers over a long period, replacing suppliers would entail higher costs, and such firms would also have less bargaining power and weaker negotiating positions in dealing with suppliers(Dhaliwal et al., 2016). Therefore, when downstream firms seek to ease their own financing constraints by adjusting the proportion of prepayments or payables, or by extending payment periods, firms with a higher degree of dependence on upstream suppliers are often less able to achieve these objectives. This study uses supply chain concentration and supply chain persistence to reflect the degree of customer dependence on suppliers.

Supply chain concentration is measured by the average of the sum of the procurement and sales ratios of the top five suppliers and customers, and the sample is divided into two groups according to whether this value is above the industry-year mean. The regression results are reported in columns (5) and (6) of Table 5. For firms with low supply chain concentration, the coefficient on the interaction term is significantly positive at the 5% level, whereas for firms with high supply chain concentration, the coefficient is positively correlated at the 10% level. This indicates that the higher the supply chain concentration, the more difficult it is for downstream firms outside the pilot zones to obtain policy benefits from upstream firms through inter-firm credit.

Supply chain persistence is measured by the average number of times each of the top five suppliers appears over the past two years. The sample is likewise divided into two groups according to whether this value is above the industry-year mean. The regression

results are reported in columns (7) and (8) of Table 5. For firms with low supply chain persistence, the coefficient on the interaction term is significantly positive at the 10% level, whereas for firms with high supply chain persistence, the coefficient is not significant. This suggests that the more persistent the relationship with suppliers, the weaker the bargaining power of downstream firms, making it similarly difficult for them to benefit from the policy spillover effects of upstream firms located in the pilot zones.

4.4.3 Environmental characteristics: environmental regulation intensity and bank competition intensity

A higher intensity of environmental regulation usually increases firms' environmental compliance pressure and significantly raises their motivation and demand for financing during the process of green transformation(De Haas and Popov, 2023). This may in turn drive firms to go beyond traditional formal financing channels and actively explore diversified or alternative financing paths to ease transformation constraints. Accordingly, this study uses the natural logarithm of the total frequency of environment-related terms in government work reports to measure regional environmental regulation intensity, and divides the sample into two groups based on whether the value is above the industry-year mean. The regression results are reported in columns (9) and (10) of Table 5. For firms located in regions where downstream customers face higher environmental regulation intensity, the coefficient on the interaction term is significantly positive at the 5% level, whereas the coefficient is insignificant for firms located in regions with lower environmental regulation intensity. This indicates that a stronger environmental regulatory environment promotes credit interaction between upstream and downstream firms in the supply chain, thereby enhancing green technology innovation spillovers to downstream firms outside the pilot zones. When environmental regulation intensity is weaker, green finance policies are less able to promote green innovation spillovers to downstream firms through inter-firm credit.

In addition, as an alternative or complementary channel to financing from traditional financial institutions (such as bank lending), inter-firm credit is to a large extent affected by the intensity of bank competition in a region. Therefore, this study uses the Herfindahl–Hirschman Index (HHI) of the banking industry in the region where downstream firms are located to measure regional bank competition intensity, and divides the firm sample into two groups according to the industry-year mean. The HHI is calculated as follows:

$$HHI=\sum_{K=1}^{K}(Branch_k/Total_{Branches})^2$$

Here, $Branch_k$ represents the number of branches established by bank k in the region, and $Total_{Branches}$ represents the total number of bank branches in that region. The value of this index ranges from 0 to 1, with a larger value indicating a lower degree of bank competition in the region. The regression results are reported in columns (11) and (12) of Table 5. The coefficient on the interaction term for regions with stronger bank competition is negative and not statistically significant, whereas the coefficient for regions with weaker bank competition is significantly positive at the 1% level. This suggests that intensified competition in the banking sector may lead to a relaxation of formal credit approval standards, thereby improving downstream firms' access to bank loans and reducing their reliance on internal informal credit channels. By contrast, when bank competition is weaker, banks tend to adopt more prudent lending standards and show less willingness to lend, making formal financing more difficult for firms to obtain. This in turn strengthens credit relationships among firms within the supply chain, making supply chain credit an important alternative financing channel.

Table 5
Heterogeneity Tests.

	Firm characteristics			
Variables	**Small and medium-sized firms**	**Large firms**	**High information disclosure quality**	**Low information disclosure quality**
	(1)	**(2)**	**(3)**	**(4)**
Shock×CI	0.195	0.316**	0.183*	0.402***
	(1.06)	(2.56)	(1.68)	(2.88)
Control variables	YES	YES	YES	YES
Fixed effect	YES	YES	YES	YES
N	952	5087	2927	2998
Adj.R-squared	0.888	0.840	0.882	0.918

	Supply chain characteristics			
	High supply chain concentration	**Low supply chain concentration**	**High supply chain persistence**	**Low supply chain persistence**
Variable	**(5)**	**(6)**	**(7)**	**(8)**

Shock×CI	0.184* (1.70)	0.431** (2.05)	0.013 (0.19)	0.379* (1.68)
Control variables	YES	YES	YES	YES
Fixed effect	YES	YES	YES	YES
N	2903	3073	2934	2502
Adj.R-squared	0.876	0.892	0.901	0.917

	Environmental characteristics			
Variable	**High environmental regulation intensity**	**Low environmental regulation intensity**	**High bank competition intensity**	**Low bank competition intensity**
	(9)	**(10)**	**(11)**	**(12)**
Shock×CI	0.427** (2.05)	0.064 (0.70)	-0.030 (-0.35)	0.664*** (3.41)
Control variables	YES	YES	YES	YES
Fixed effect	YES	YES	YES	YES
N	2494	1999	2390	2882
Adj.R-squared	0.874	0.898	0.883	0.819

5 Conclusion and Policy Implications

5.1 Conclusion

As an important instrument for promoting the green transformation of the real economy, green finance policies can generate green innovation spillovers that extend to other firms within the supply chain located outside policy-covered areas. Using supplier–customer data from supply chains, this study examines the cross-regional innovation spillover effects of green finance policies along supply chains. The main findings are as follows: (1) the establishment of green finance pilot zones in the regions where upstream supply chain firms are located significantly promotes green innovation among downstream firms outside the pilot zones, confirming the existence of a cross-regional spillover effect of green finance policies; this finding remains robust across a series of robustness checks. (2) The establishment of green finance pilot zones significantly alleviates financing constraints for firms within the pilot zones. On this basis, credit transmission among supply chain firms provides a channel for capital flows, enabling the incentive effects generated by green finance policies to spill over to downstream firms outside the pilot zones. (3) Further analysis reveals that the cross-regional green innovation spillover effect driven by positive corporate credit transmission is influenced by multiple factors at the firm, supply chain, and environmental levels,

including firm size, information disclosure quality, supply chain concentration, supply chain stability, environmental regulation intensity, and bank competition intensity.

5.2 Policy Implications

To fully leverage the cross-regional innovation spillover effects of green finance policies and promote the green transformation of the real economy, this study proposes the following policy recommendations. First, it is necessary to strengthen the cross-regional coordination and diffusion mechanisms of green finance policies so as to enhance their spillover effects. While continuing to advance the construction of green finance pilot zones, the government should pay greater attention to breaking down policy barriers across regions, establishing cross-regional platforms for green finance cooperation and information sharing, and guiding financial resources to flow along supply chains in an orderly manner. By improving supporting incentive measures and related mechanisms, local policy advantages can be transformed into broader institutional dividends, thereby promoting green innovation among firms outside the pilot zones and fostering a supply chain-based pattern of coordinated green transformation.

Second, the positive transmission effect of inter-firm credit should be strengthened in order to improve the supply chain diffusion capacity of green finance policies. While paying attention to the improvement of financing conditions for firms within pilot zones, policymakers should also attach importance to the reallocation function of financial resources within supply chains. Through institutional guidance and financial incentives, firms that enjoy financing advantages can be encouraged to transform their funding advantages into credit support and cooperative incentives for upstream and downstream firms, thereby promoting the formation of a supply chain-linked financing mechanism. As the intensity of inter-firm credit transmission increases, the scope of green finance policies can expand from isolated points to chain-like diffusion, thus more effectively encouraging firms outside the pilot zones to engage in green innovation and improving the overall efficiency and spillover value of policy implementation.

Third, the external environment for inter-firm credit transmission should be optimized in order to consolidate the institutional foundation for green innovation spillovers. The government should continue to improve the environmental regulation system so as to provide a clear institutional orientation for corporate green transformation, while also enhancing competition in the banking sector to encourage financial institutions to improve credit allocation efficiency and service quality. In addition, efforts should be made to strengthen the construction of a market-oriented credit system, reduce

information asymmetry, and improve the overall financing environment for firms. In this way, firms can obtain stable financial support in a more standardized, transparent, and competitively ordered financial environment, thereby creating favorable external conditions for green finance policies to generate innovation spillovers along supply chains.

5.3 Limitations and Future Research Directions

The analysis is conducted in the context of China's green finance pilot zone policy, which provides a valuable setting for identifying policy-induced financial incentives, but may also limit the generalizability of the conclusions to other institutional environments. Differences in financial systems, regulatory structures, and supply chain governance across countries may shape both the strength and the channels of policy spillovers. Future research could conduct cross-country comparisons or explore other green policy settings to assess whether the spillover mechanism identified in this study also operates in different institutional and market contexts.

Overall, this study provides new evidence that green finance policies may extend beyond policy-covered regions and generate cross-regional green innovation spillovers through supply chain networks. It is hoped that future research can build on this framework to further uncover the broader transmission logic, boundary conditions, and sustainability implications of policy-driven financial incentives.

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