参赛学生姓名：王沃天 Austin Wang

中学：上海市民办平和学校

省份：上海

国家/地区：中国

指导老师姓名：王亮

指导老师单位：湘潭大学商学院

论文题目：Taming the Green Swan: Does Green Finance Reduce Corporate Biodiversity Risk along Supply Chains? Evidence from China’s Green Finance Pilot Zones

# Taming the Green Swan: Does Green Finance Reduce Corporate Biodiversity Risk along Supply Chains? Evidence from China's Green Finance Pilot Zones

**Abstract:** This paper investigates whether China's Green Finance Reform and Innovation Pilot Policy reduces corporate biodiversity risk and its propagation along supply chain networks. Using a quasi-natural experiment with all A-share listed companies from 2012–2023, we employ a difference-in-differences (DID) design to identify the policy's impact on firm-level biodiversity risk. We find that the green finance pilot policy significantly reduces the biodiversity risk of firms headquartered in pilot zones (the "focal" firms). Moreover, this risk-mitigating effect spills over downstream: the biodiversity risk of customer firms connected to treated central firms also declines relative to peers. We explore the mechanisms and find evidence for both external-pressure and internal-incentive. External mechanisms include enhanced monitoring pressure for pilot firms. Internal mechanisms involve stimulated breakthrough green innovation. These above channels also partially induce downstream firms to lower their biodiversity risk. Heterogeneity analysis shows that the risk mitigation effect is more pronounced for focal firms that are larger, in more competitive industries, or under weaker local environmental regulation. Likewise, downstream firms that are smaller, have poorer resource endowments, or are geographically closer to the central firms experience stronger biodiversity risk reduction. Further analyses reveal additional benefits of the pilot policy strengthens supply chain resilience, improves firm performance, and lowering stock price crash risk. We also find that the policy-induced biodiversity risk reduction extends to lower-tier downstream firms, indicating a multi-level spillover along the supply chain. Our findings highlight the important role of green finance policies in "taming the green swan" mitigating systemic environmental risks through supply chain networks.

**Keywords**: Green finance; Biodiversity risk; Supply chain spillover; Green innovation; Environmental regulation policy.

**JEL classifications:** G12; G14; G30; H54.

## Contents

## 1. Introduction

Climate change and biodiversity loss have emerged as critical risks to the global economy and financial system. Unprecedented environmental degradation – from rising greenhouse gas concentrations to collapsing ecosystems – has led policymakers and scholars to warn of so-called "green swan" events: rare but potentially catastrophic environmental shocks that can trigger systemic financial crises. The term Green Swan, coined by the Bank for International Settlements, underscores the radical uncertainty and far-reaching impact of climate- and nature-related risks on financial stability. Biodiversity loss, in particular, poses profound economic threats. The World Economic Forum estimates that over half of global GDP (approximately $44 trillion) is moderately or highly dependent on nature and its services.

The collapse of ecosystems – through the extinction of species, loss of pollinators, degradation of soils and oceans – can disrupt supply chains, reduce resource availability, and impose large costs on businesses and society (Giglio et al., 2023). Recognizing these dangers, regulators and investors worldwide are increasingly focused on biodiversity-related financial risks. For example, the Network for Greening the Financial System (NGFS) and the Taskforce on Nature-related Financial Disclosures (TNFD) have called for integrating nature-related risks into financial oversight and corporate reporting (NGFS, 2022; TNFD, 2023).

In capital markets, emerging research shows that firms with greater biodiversity risk exposure face higher financing costs and lower valuations as investors begin to price in nature-related risks (He et al., 2024; Bassen et al., 2024). Recent evidence from China finds that firms more vulnerable to biodiversity loss earn significantly lower stock returns and attract less institutional ownership, and that increased disclosure of biodiversity risks can reduce stock price crash risk by improving transparency (Wang, 2025; Bassen et al., 2024). In short, biodiversity risk has become a material concern for both financial stability and firm value, demanding innovative solutions.

Against this backdrop, green finance has risen as a key strategy to align financial flows with environmental sustainability and to mitigate "green swan" risks. Green finance refers to financial instruments, policies, and institutional arrangements that incentivize investment in environmentally friendly projects and dis-incentivize polluting activities (OECD, 2017). By leveraging market mechanisms and policy support, green finance aims to reconcile economic growth with ecological conservation, channeling capital toward renewable energy, pollution control, biodiversity protection, and other green initiatives (Huang et al., 2023). In theory, a robust green financial system can correct environmental externalities by incorporating ecological considerations into lending, investment, and insurance decisions (Fu et al., 2024; Liu & Xiong, 2022). This not only helps reduce environmental degradation but also protects the long-term value of financial assets from climate and biodiversity risks (Azar et al., 2021).

What remains less understood is whether and how such green finance policies translate into reduced environmental risks at the firm level, especially biodiversity-related risk, and how any benefits might spread through supply chain networks. Biodiversity risk in a corporate context can be defined as the potential financial and operational losses a firm faces due to its impact and dependence on ecosystems and natural resources (WEF, 2020; Pi et al., 2025). Firms in certain sectors (e.g. agriculture, forestry, mining, chemicals) or with operations in ecologically sensitive areas are particularly exposed to biodiversity risks – from regulatory fines and litigation over habitat destruction, to supply disruptions as natural resources become scarce, to reputational damage and loss of market access as stakeholders demand sustainable practices (Treepongkaruna et al., 2024). However, academic research on corporate biodiversity risk mitigation is still nascent. In particular, no prior study (to our knowledge) has causally identified the impact of a government-led green finance initiative on corporate biodiversity risk, making our investigation timely and novel.

This paper addresses this gap by examining the Green Finance Reform and Innovation Pilot Policy's effect on biodiversity risk at the firm level, as well as its indirect effects along supply chains. China provides a salient context to examine the effectiveness of green finance in mitigating biodiversity risk. Over the past decade, China's rapid industrialization has incurred severe environmental costs – from chronic air and water pollution to biodiversity loss – spurring the government to integrate environmental objectives into financial regulation (PBoC, 2016; Liu & Xiong, 2022). A landmark policy was the Green Finance Reform and Innovation Pilot program launched in June 2017. In this program, the State Council designated eight pilot zones across five provinces (Zhejiang, Guangdong, Jiangxi, Guizhou, and Xinjiang) to spearhead green financial reform. Each pilot zone was tasked with developing innovative green finance mechanisms – such as green credit, green bonds, environmental risk insurance, and specialized green funds – to support local ecological protection and sustainable development.

We examine whether China's Green Finance Reform and Innovation Pilot Policy reduces corporate biodiversity risk and its propagation along supply chain networks. Leveraging a quasi-natural experiment covering all A-share listed companies from 2012–2023, we implement a difference-in-differences (DID) design to identify the policy's effect on firm-level biodiversity risk. We find that the green finance pilot policy significantly lowers the biodiversity risk of firms headquartered in pilot zones (the "focal" firms). Moreover, the risk-mitigating effect spills downstream: the biodiversity risk of customer firms connected to treated central firms also declines relative to peers. We probe the mechanisms and find evidence for both external and internal channels. External mechanisms include heightened monitoring pressure on pilot firms, while internal mechanisms involve stimulated breakthrough green innovation. These channels also partially induce downstream firms to reduce their biodiversity risk.

Heterogeneity analysis shows that the risk-mitigation effect is more pronounced for focal firms that are larger, operate in more competitive industries, or are subject to weaker local environmental regulation. Likewise, downstream firms that are smaller, have poorer resource endowments, or are geographically closer to the central firms experience stronger reductions in biodiversity risk. Further analyses reveal additional benefits: the pilot policy strengthens supply chain resilience, improves firm performance, and lowers stock price crash risk. We also find that the policy-induced biodiversity risk reduction extends to lower-tier downstream firms, indicating a multi-level spillover along the supply chain.

In summary, our study makes several contributions to the literature.

First, we provide novel micro-evidence on the effectiveness of green financial policy in reducing corporate biodiversity risk – an area of growing importance but limited prior research. We bridge the gap between macro-level environmental finance (most prior studies on China's green finance pilots focus on regional pollution or green investment aggregates) and firm-level risk outcomes, especially the underexplored biodiversity dimension (Remades & Fuertes, 2023; Li et al., 2024; Liu et al., 2024).

Second, we highlight the role of supply chain networks in amplifying policy impacts. By documenting forward spillovers of risk reduction and environmental performance improvements, we enrich the literature on environmental spillovers and sustainable supply chain management (Bartelsman et al., 1994; Choi et al., 2020; Herkenhoff et al., 2024). This multi-tier perspective underscores that greening a supply chain's focal firms can cascade benefits to connected firms, an insight relevant for policymakers and large corporations aiming to improve sustainability across their value chain (Ettl et al., 2000; Cheng & Nault, 2007).

Third, we shed light on the mechanisms – both external pressures and internal innovations – through which green finance policies operate. Our evidence on monitoring pressure and financing constraints complements prior work on the importance of transparency and capital access for environmental outcomes (Shi et al., 2022; Wang & Chen, 2022; Zhang & Lu, 2022). Likewise, our findings on green innovation support and extend the Porter Hypothesis in the context of financial policy instruments (Porter & Linde, 1995; Liu & Xiong, 2022; Xu et al., 2023).

Fourth, we broaden the evaluation of green finance by examining ancillary outcomes like resilience, CSR, and crash risk, which connect environmental performance to broader corporate stability and investor interests (Herkenhoff et al., 2024; Bassen et al., 2024; Testa et al., 2025). These results suggest that green financial reforms can simultaneously advance environmental objectives and risk management without sacrificing (and possibly enhancing) firm value – a win–win for sustainable development and financial stakeholders (Aziz et al., 2022; Xu et al., 2025).

The rest of this paper is organized as follows. Section 2 reviews the related literature and develops our hypotheses. Section 3 describes the empirical methodology design, covering data sources, variable definitions, and the econometric specifications, with particular attention to the DID framework. Section 4 presents the baseline regression results and a series of robustness checks. Section 5 conducts mechanism analysis, focusing on the external-pressure and internal-incentive channels for focal firms, and the financing-capacity and green-innovation channels for downstream firms. Section 6 explores heterogeneous effects, such as firm size, industry competition, environmental regulation, geographic distance, and resource endowment. Section 7 provides further discussion of the consequences, including multitier supply-chain spillovers and economic outcomes such as resilience, operating performance, reputational capital, and stock-price crash risk. Finally, Section 8 concludes with a summary of findings, managerial and policy implications, and limitations with directions for future research.

## 2. Literature review and hypothesis development

### 2.1 Literature review

This study builds on several streams of literature. The first pertains to the impact of green finance and environmental policies on corporate behavior. A growing body of work examines how government policies that integrate environmental objectives into financial systems affect firm outcomes. In China, the Green Credit Guidelines issued in 2012 directed banks to tighten lending to heavy polluters and support green projects (China Banking Regulatory Commission, 2012). Empirical studies show that the policy increased financing constraints for polluting firms, reduced their access to bank debt, and curtailed investment (Shi et al., 2022; Wang & Chen, 2022). Consistent with this mechanism, affected firms experienced lower profitability and adjusted their capital allocation toward cleaner operations (Zhang & Lu, 2022).

Relatedly, research on green bonds finds that firms issuing corporate green bonds subsequently improve environmental performance and attract more long-term investors without negative stock return effects, suggesting investors value credible commitments to green projects (Aziz et al., 2022).

Specific to the Green Finance Reform and Innovation Pilot Zones established from 2017 onward, recent studies document multiple benefits. At the city level, pilot zones significantly reduced air pollution ($PM_{2.5}$/AQI), with mechanisms operating through industrial structure upgrading and green innovation (Zhang et al., 2023; Luo et al., 2024). At the firm level, the pilot policy improved corporate investment efficiency by curbing inefficient and excessive investments (Yan et al., 2022), and raised firms' ESG scores (Pi et al., 2025). Green innovation is a focal outcome: evidence shows that the pilot zones increased both the quantity and quality of green patents (Liu & Xiong, 2022; Xu et al., 2023), with notable regional heterogeneity—effects being strongest in Zhejiang/Guangdong and weaker in Xinjiang (Li et al., 2024). Financial consequences also changed: banks appear to reward improved environmental behavior, as heavy polluters in pilot zones faced lower debt financing costs via a reputation-insurance (signal) channel (Shi et al., 2022).

At a broader level, the pilot zones contributed to regional green development through industrial upgrading and technological innovation (Remades & Fuertes, 2023; Xu et al., 2025). In summary, China's green finance policies—especially the pilot zones—have generally improved environmental outcomes and nudged firms toward greener practices. However, most studies still pay limited attention to biodiversity-specific risks or supply-chain interactions, which is where our paper seeks to contribute.

### 2.2 Hypothesis development

#### *2.2.1 The effect of Green Finance Pilot on Biodiversity Risk of focal firms*

Our work also intersects with the emerging literature on biodiversity risk and corporate finance. Biodiversity risk refers to the potential negative impacts on a firm's operations or value stemming from biodiversity loss or ecosystem degradation. This can manifest in various forms: operational disruptions (e.g., loss of ecosystem services such as water purification or flood control affecting facilities), regulatory sanctions (new laws protecting habitats can restrict business activities), market and supply chain shocks (scarcity of natural inputs, or consumer boycotts of products linked to deforestation), and reputational or litigation risks (firms held accountable for harming biodiversity). Historically, climate change has dominated environmental risk discussions in finance (e.g., "BR risk" and the pricing of BR emissions, as in Bolton and Kacperczyk 2021), but biodiversity is now gaining attention as an equally critical dimension (NGFS-INSPIRE 2022).

Recent studies provide initial evidence of how biodiversity risk is being perceived in financial markets. Chen et al. (2024) develop novel measures of biodiversity risk exposure for Chinese companies and show that firms with higher biodiversity risk had lower stock returns in recent years. This implies that investors required a premium (higher expected returns) to hold stocks of biodiversity-exposed firms, possibly anticipating future losses or regulations hitting those firms. Moreover, the negative return effect was stronger in periods of heightened aggregate attention to biodiversity issues, suggesting that as public and investor awareness of biodiversity loss increases (e.g., around major UN conferences or release of landmark reports), the market more sharply differentiates firms based on biodiversity footprint . Garel et al. (2024), in a global sample, introduce a

“Corporate Biodiversity Footprint” metric that quantifies a firm’s impact on biodiversity (using a Mean Species Abundance approach). They find that until very recently, this footprint was not strongly priced into stock returns on average, but after late 2021 – around the time of the Kunming Declaration (COP15 Part 1) – investors started to penalize firms with worse biodiversity footprints, anticipating greater regulatory or reputational risks for those firms. Specifically, they observed that stocks with high biodiversity footprint underperformed following the global increase in biodiversity policy momentum, consistent with a rising biodiversity risk premium. This aligns with anecdotal evidence of investors beginning to integrate nature-related criteria into their decisions, similar to how BR risk became a mainstream concern a few years earlier (University of Cambridge Institute 2022). In the corporate debt market, Duong et al. (2025) find that firms with higher biodiversity risk (e.g., operating in biodiversity-sensitive sectors or regions) tend to avoid short-term debt, indicating that managers perceive biodiversity risk as a long-term issue and try to push debt maturities outward to mitigate refinancing risk in the face of potential biodiversity-related shocks. This is an interesting behavioral response showing that corporate financing strategy may adapt to underlying environmental risk exposure. Another study by Ning and Yasuda (2025) focuses on biodiversity risk disclosure and finds that firms which voluntarily disclose more information about their biodiversity-related risks and conservation efforts see a subsequent reduction in their stock price crash risk (a measure we also analyze). This suggests that transparency around nature risks can reassure investors and reduce asymmetry, lowering extreme downside risk in equity prices – analogous to how financial or BR disclosure can reduce crash risk (Kim et al. 2014; Jung et al. 2018).

The above literature underscores that biodiversity risk is financially relevant and that both firm actions (innovation, disclosure, strategy) and investor behavior are starting to reflect this. However, a key question is: what can drive firms to proactively reduce their biodiversity risk? One factor could be regulatory or policy interventions that compel or incentivize firms to manage natural capital more sustainably. While hard environmental regulations (like protected areas, quotas on resource extraction, or endangered species laws) directly push firms to reduce biodiversity impacts, those typically lie outside financial economics research. Our focus is on a financial policy (green finance) that might indirectly achieve similar outcomes by shifting how firms get capital and at what cost. If green finance policy effectively channels funds to less ecologically harmful activities and conditions financing on environmental performance, it stands to reason that firms will take steps to lower their biodiversity risk profile (to qualify for finance and to leverage the support for relevant investments). This mechanism has not been explicitly studied before – we aim to fill that gap by testing whether the green finance pilot policy led to measurable reductions in firm-level biodiversity risk.

We hypothesize that it did, formulating our first hypothesis as follows:

**H1**: The Green Finance Reform and Innovation Pilot Policy significantly reduces the biodiversity risk of firms in the pilot zones (treated "focal" firms), relative to similar firms not subject to the pilot policy.

*2.2.2 The spillover effect of Green Finance Pilot on Biodiversity Risk of downstream firms*

A distinct but related literature examines supply chain spillovers and diffusion of practices between firms. In management and operations research, the concept of inter-firm environmental spillovers has been widely discussed (Bartelsman et al., 1994; Cheng & Nault, 2007). This stream of work posits that a company's environmental performance is interconnected with that of its suppliers and customers. Leading firms often extend their sustainability requirements upstream to suppliers via green procurement standards, supplier audits, and assistance programs, ensuring that inputs are produced in an eco-friendly manner. Downstream, firms also collaborate with customers on eco-design of products, recycling initiatives, and take-back programs to reduce lifecycle impact. These practices imply that improvements in one part of the chain can influence others.

Empirical studies have found evidence of such spillovers: for example, Choi, Özer, and Zheng (2020) show that trust and relational dynamics within supply chains significantly affect cooperation and innovation outcomes, suggesting that environmental strategies can diffuse through network ties. Herkenhoff et al. (2024) further document that corporate social responsibility (CSR) practices travel along global value chains, showing measurable spillover effects from focal firms to their partners. Similarly, Ettl et al. (2000) develop a supply network model demonstrating how policies or operational requirements imposed by central firms cascade through supplier and customer tiers.

These works align with broader theories of inter-firm influence, where a central firm's strategy and reputation can affect peers and partners (Dyck, Volchkova, & Zingales, 2008; Xu et al., 2016). Given these dynamics, it is plausible that a policy impacting a subset of firms could have multiplier effects via supply chain links. In our context, firms in pilot zones that improve their environmental profile might impose or inspire changes in their supply chain partners. On the upstream side, a treated firm might encourage its raw material suppliers to adopt sustainable harvesting or reduce pollution, else the firm may switch to more sustainable suppliers (thereby indirectly spreading the policy's influence upstream). On the downstream side, a treated supplier offering greener products (e.g., materials made with less ecological damage) directly reduces the downstream firm's own environmental footprint. Additionally, if the downstream firm observes the supplier benefiting from green finance (cheaper credit, etc.), it may seek to emulate some of those practices to qualify for similar benefits (especially if it is in a region that might get future policies). Over time, the entire chain could become greener and less exposed to biodiversity risk. We note that spillover could also go in the other direction (upstream). However, our study focuses on downstream because the data on customer relationships is often more readily available (major customers must be disclosed in financial reports for listed firms in China, whereas suppliers are disclosed less often unless they are also listed).

Thus, we posit a second hypothesis:

**H2**: The Green Finance Pilot Policy has a forward supply chain spillover effect, meaning that downstråeam firms (customers) linked to treated firms also experience a reduction in biodiversity risk compared to other firms, as a result of their supply chain connection.

*2.2.3 The spillover effect of Green Finance Pilot on Biodiversity Risk of upstream firms*

By contrast, the green-finance pilot policy centered on focal (central) firms generates only limited spillovers in alleviating upstream firms' biodiversity risk. First, managing biodiversity risk typically entails sustained investments in ecological monitoring (e.g., baseline surveys and long-term monitoring), supply-chain traceability and certification, raw-material substitution, and habitat restoration—characterized by high upfront fixed costs, long investment cycles, and uncertain returns. Because upstream firms are farther from end markets and consumers, media, NGO, and investor scrutiny is comparatively weak; with insufficient external incentives, they have limited intrinsic motivation to shoulder additional ecological-governance costs. Second, upstream stages are often resource-intensive or supply intermediate inputs, with strong technological path lock-in and asset specificity; minor process tweaks rarely yield sizable short-run reductions in ecosystem disturbance, resulting in weak incentives to curb biodiversity risk. Third, vertical information asymmetries are more pronounced upstream: gaps in risk identification, quantification, and disclosure impede the effective diffusion and internalization of focal firms' environmental information and green capabilities.

From an industrial-economics perspective, constraints imposed by input–output linkages also weaken the basis and conditions for upstream firms to capture rent spillovers (Cheng & Nault, 2007). Potential spillovers between focal and upstream firms are largely demand-driven externalities: adjustments triggered by order specifications or compliance requirements tend to be short-term and tactical, with limited impact on long-term capability building and substantive ecological performance (Bartelsman et al., 1994). Consequently, relative to the knowledge and managerial spillovers that more readily accrue to downstream firms, the policy propagates weakly upstream; absent hard constraints—such as stringent green-procurement clauses, supplier certification, and audits—upstream firms are unlikely to achieve material and sustained reductions in biodiversity risk.

Thus, we posit a third hypothesis:

**H3**: The Green Finance Pilot Policy shows limited backward supply-chain spillover, meaning that upstream suppliers connected to treated focal firms do not experience a statistically discernible reduction in biodiversity risk, on average, compared with comparable unconnected suppliers

## 3. Empirical methodology design

### 3.1 Data materials and sample preparation

We primarily use three datasets:

(1) Firm financial and operating data: cost of goods sold, operating revenue, and financial-statement items drawn from the China Stock Market & Accounting Research database (CSMAR).

(2) Supply-chain data: lists of the top five suppliers and customers for listed companies from the China Research Data Services platform. For completeness, when this source contains missing entries, we supplement the focal firm's top five trading partners using Tianyancha, iFinD, and Choice terminals.

(3) Annual-report texts (for constructing firm biodiversity risk). We scrape and clean annual reports of Mainland China A-share listed companies and apply a dictionary-based text-as-data approach to obtain a continuous firm-level measure of biodiversity risk. The dictionary and measurement follow the biodiversity word lists and firm-level exposure construction proposed by Giglio et al. (2023) and He et al. (2024), adapted to Chinese annual reports; the Chinese implementation and empirical procedures for the China sample follow He et al.'s (2024) study and data documentation. To harmonize terminology and enhance comparability, keyword selection and mapping are aligned with the glossaries of the Taskforce on Nature-related Financial Disclosures (TNFD, n.d.) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, n.d.).

For listed-company samples from 2012-2023, we follow standard filters: we exclude firms in the financial industry, firms under special treatment (ST/*ST), and observations with missing key variables, yielding 23,919 firm-year observations for focal firms. After extending supply-chain links, we obtain 2,578 upstream and 1,924 downstream firm-pair observations.

### 3.2 Main variables definitions

*3.2.1 Dependent variable：Firm Biodiversity Risk（labelled “BR”）*

Firm Biodiversity Risk is measured from listed companies’ annual reports as the share of biodiversity-related sentence in the full text. This text-based exposure captures how strongly a firm’s disclosures reflect dependencies, impacts, and risks related to biodiversity and ecosystems (Giglio et al., 2023; Chen et al., 2024).

The term set is anchored on the biodiversity dictionary provided by Giglio et al. (2023)—including, for example, biodiversity, ecosystem, habitat, species, invasive species, deforestation, wetland, mangrove, coral reef, seagrass meadow, freshwater, marine, ecosystem services, and biosphere—and is adapted to Chinese annual reports through synonym mapping. Following the guidance in Giglio, Kuchler, Stroebel, and Zeng (2023), terms that refer purely to climate rather than biodiversity are excluded to avoid construct contamination. Terminology is aligned with the Taskforce on Nature-related Financial Disclosures and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services glossaries to ensure consistency of meaning across firms and time. The Chinese characters and the corresponding English characters of the related terms are presented in Appendix A.

Annual reports are parsed and cleaned by removing boilerplate material (tables, captions, repeated headers and footers), normalizing case and encoding, segmenting Chinese text, and merging close synonyms (for example, ecological system versus ecosystem; coral versus coral reef). This pipeline mirrors the Chinese annual-report implementation in Chen et al. (2024).

This paper counts the number of cases wherein risk-related terms coexist with terms pertaining to biodiversity within the same sentence. This count is then normalized by the length of the MD&A report. Formally defined, the BR index for firm i in year t is computed in accordance with equation (1).

$$BR_{it} = \frac{1}{T_{it}} \sum_{w=1}^{R_{it}} \left\{ 1\left[ w \in terms^{Biodiversity\ Risk} \right] \times [w - r] \le One\ Sentence \right\} \qquad (1)$$

where w=1, …, $R_{it}$ is the total number of words in the MD&A text of firm i in year t. The length of report $T_{it}$ is measured as the total number of sentences in the MD&A text, and r is the position of the nearest uncertainty-related terms (i.e., r ∈ $terms^{Biodiversity}$). According to equation (1), the BR index counts the number of cases wherein risk-related terms coexist with terms pertaining to biodiversity within the same sentence. We define a list of terms related to biodiversity and uncertainty based on the related literature (Giglio et al., 2023; Chen et al., 2024). The Chinese characters and the corresponding English characters of the related terms are presented in Appendix A.

*3.2.2 Core explanatory variable: Green Finance Reform and Innovation Pilot (Grefin)*

In 2017, China's State Council officially approved the *Overall Plan for Establishing Green Finance Reform and Innovation Pilot Zones* and created pilot zones in five provinces/regions: Zhejiang, Guangdong, Xinjiang Uygur Autonomous Region, Guizhou, and Jiangxi. Additional pilot zones were subsequently established in Gansu (2019) and Chongqing (2022). *Grefin* is a dummy variable indicating whether city $j$ in year $t$ has been designated as a Green Finance Reform and Innovation Pilot Zone: *Grefin* = 1 if designated, and 0 otherwise.

*3.2.3 Control variables*

Drawing on Altman (1968), Xu et al (2023) and Dickinson (2011), we include governance-level controls—firm size (Size), CEO duality (Dual), and firm age (FirmAge)—as well as financial controls—cash flow ratio (Cashflow), book-to-market ratio (BM), Tobin's Q (TobinQ), and revenue growth (Growth). Definitions of the main variables are provided in Table 1.

**Table 1.** Variable definitions

| Group | Symbol | Variable name | Definition |
|---|---|---|---|
| Dependent variable | BR | Corporate biodiversity risk level | See main text (construction of Biodiversity Risk, BR). |
| Explanatory variable | Grefin | Green Finance Reform and Innovation Pilot | See main text. |
| Control variables | Size | Firm size | Natural log of total assets at year-end. |
| | Growth | Revenue growth | (Current-year operating revenue / Prior-year operating revenue) − 1. |
| | Cashflow | Cash flow ratio | Net cash flow from operating activities / Total assets. |
| | Dual | CEO duality | 1 if the board chair and the general manager (CEO) are the same person; 0 otherwise. |
| | FirmAge | Firm age | ln(Current year − Year of incorporation + 1). |
| | BM | Book-to-market ratio | Book value / Market capitalization. |
| | TobinQ | Tobin's Q | (Market value of tradable shares + Number of non-tradable shares × Net asset per share + Book value of liabilities) / Total assets. |

### 3.3 Econometric Specification: Difference-in-Differences (DID) Model

*3.3.1 Green-Finance Pilot Policy and Focal Firms' Biodiversity Risk*

We estimate the following model to examine how the pilot policy affects focal firms' BR:

$$BR_{ijt} = \alpha_0 + \alpha_1 Grefin_{jt} + \alpha_2 X_{ijt} + u_i + \theta_t + \varepsilon_{ijt} \qquad (2)$$

where $BR_{ijt}$ is the biodiversity risk of focal firm i in city j and year t; $Grefin_{jt}$ indicates whether city j implements the Green-Finance Reform and Innovation pilot in year t; $X_{ijt}$ is a vector of controls. We include firm fixed effects ($u_i$) and year fixed effects ($\theta_t$). Standard errors are clustered at the firm level; $\varepsilon_{ijt}$ is the error term.

*3.3.2 Green Finance and Biodiversity Risk Along the Supply Chain*

Building on the effect for focal firms, we further assess the impact on upstream and downstream partners:

$$BR_{kjt} = \alpha_0 + \beta_1 Grefin_{jt} + \beta_2 Clientpolicy_{jt} + \beta_3 X_{kjt} + u_i + \theta_t + \varepsilon_{kjt} \qquad (3)$$

where $BR_{kjt}$ denotes the biodiversity risk of supplier/customer k linked to focal firm i (city j) in year t; $Grefin_{jt}$ is defined as above; $Clientpolicy_{jt}$ if the supplier/customer's registered location is in a pilot zone in year t (0 otherwise); $X_{ijt}$ is the control vector for firm k. All regressions include firm and year fixed effects.

## 4. Empirical results

### 4.1 Baseline regression results

Whether the green-finance pilot policy can alleviate focal firms' biodiversity risk is pivotal to greening supply chains and constitutes the basis for any upstream and downstream spillovers of risk mitigation. Accordingly, we first examine the policy's impact on focal firms' biodiversity risk. Columns (1)–(2) of Table 2 report the estimates for focal firms. Column (1), which omits fixed effects and controls, shows a significant negative association between the policy and focal-firm biodiversity risk. After adding fixed effects and covariates to mitigate omitted-variable bias, the Column (2) regression indicates that the policy significantly reduces focal-firm biodiversity risk.

Columns (3)–(4) of Table 2 present the results for downstream firms. Column (3), without fixed effects or controls, reveals a significant negative relationship. When firm/year fixed effects and relevant controls are included in Column (4), the coefficient attenuates in absolute value but remains significantly negative. This pattern indicates that the policy substantially lowers downstream firms' biodiversity risk, consistent with a pronounced forward spillover.

**Table 2. Baseline regression results**

| Variables | (1) Focal Firms | (2) Focal Firms | (3) Downstream Firms | (4) Downstream Firms | (5) Upstream Firms | (6) Upstream Firms |
|---|---|---|---|---|---|---|
| | *BR* | *BR* | *BR* | *BR* | *BR* | *BR* |
| *Grefin* | -0.688** | -0.274*** | -22.104*** | -17.842** | -23.451 | -3.485 |
| | (0.331) | (0.088) | (7.628) | (7.320) | (21.980) | (12.602) |
| *Clientpolicy* | | | 7.412 | -3.988 | 66.428 | 24.819 |
| | | | (16.910) | (20.541) | (54.912) | (23.756) |
| *Dual* | | 0.071*** | | -7.833* | | -12.318 |
| | | (0.023) | | (4.546) | | (7.982) |
| *Size* | | 0.352*** | | 22.991*** | | 41.872*** |
| | | (0.079) | | (3.215) | | (2.658) |
| *Cashflow* | | 0.228 | | -12.211 | | 2.612 |
| | | (0.252) | | (19.881) | | (38.721) |
| *BM* | | -0.173 | | 8.214 | | 27.004 |
| | | (0.268) | | (12.443) | | (16.881) |
| *TobinQ* | | 0.025*** | | 1.802 | | 2.318 |
| | | (0.008) | | (2.098) | | (1.922) |
| *Growth* | | 0.003* | | 6.514 | | 3.992 |
| | | (0.002) | | (5.286) | | (5.612) |
| *FirmAge* | | -0.704** | | -14.592* | | -7.446 |
| | | (0.318) | | (8.720) | | (16.592) |
| Constant | 1.048*** | -4.732*** | 66.212*** | 469.312*** | 106.311*** | 929.204*** |
| | (0.317) | (1.512) | (7.954) | (82.716) | (9.318) | (77.122) |
| Year FE | No | Yes | No | Yes | No | Yes |
| Firm FE | No | Yes | No | Yes | No | Yes |
| observation | 23,919 | 23,919 | 2,578 | 2,578 | 1,924 | 1,924 |
| Adjust $R^2$ | 0.089 | 0.901 | 0.076 | 0.812 | 0.045 | 0.802 |

Notes: Robust standard errors in parentheses. The same applies to subsequent tables.

Columns (5)–(6) of Table 2 report the estimates for upstream firms. The results show no statistically significant reduction in upstream biodiversity risk, suggesting that the backward spillover is not evident.

## 4.2 Robustness checks

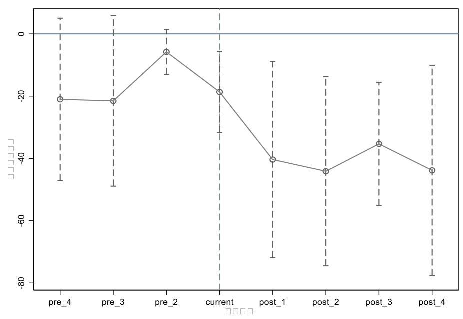
### *4.2.1 Parallel trend test*

We examine the policy's dynamic effects using an event-study specification:

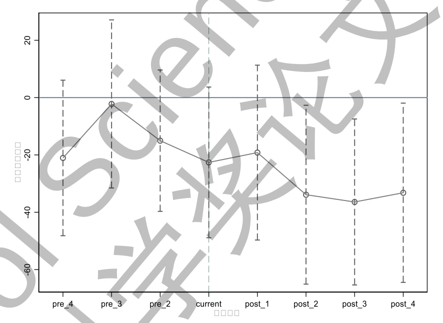
$$BR_{ijt} = \alpha_0 + \sum_{i \geq -4,\ m \neq -1}^{4} \alpha_m Grefin\_D_{jt}^{m} + +\alpha_n X_{ijt} + u_i + \theta_t + \varepsilon_{ijt} \quad (4)$$

$$BR_{kjt} = \beta_0 + \sum_{k \geq -4,\ m \neq -1}^{4} \beta_m Grefin\_D_{jt}^{m} + +\beta_n X'_{kjt} + u_i + \theta_t + \varepsilon_{kjt} \qquad (5)$$

where $Grefin\_D_{jt}^{m}$ is a relative-time indicator equal to 1 if city j (or k) is m years from the establishment of the green-finance pilot zone in year T (i.e., t-T=m), and 0 otherwise. We bin the endpoints so that $Grefin\_D_{jt}^{4}$=1 when t-T>=4 and $Grefin\_D_{jt}^{4}$=1 when t-T<=-4. The period m=-1 (the year just before implementation) is omitted as the reference.




（a）**Parallel-trend test（Focal Firms）**




（b）**Parallel-trend test（Downstream Firms）**

**Figure 1. Parallel-trend test.**

Prior to the policy, biodiversity risk (BR) for focal firms and their downstream counterparts in treated versus control groups does not differ significantly, supporting the parallel-trend assumption. Following implementation, BR in pilot areas declines markedly, indicating a significant negative policy effect. We also find evidence of a lagged transmission of the policy to downstream firms' BR.

*4.2.2 Alternative Measurement of the Explanatory Variable*

To accommodate potential lagged effects, we follow Callaway & Sant'Anna (2021), De Chaisemartin & d'Haultfoeuille (2020), and Baker, Larcker, & Wang (2022) and use a one-year lag of the pilot indicator (L.Grefin).

**Table 3.** Alternative Measurement of the Explanatory Variable

| Variables | (1) | (2) | (3) |
|---|---|---|---|
| | Alternative Measurement of the Explanatory Variable | | |
| | Focal Firms | Upstream Firms | Downstream Firms |
| | *BR* | *BR* | *BR* |
| *L.Grefin* | -0.295*** | -9.650 | -12.740** |
| | (0.113) | (11.971) | (6.141) |
| *L.Clientpolicy* | | 3.500 | -1.100 |
| | | (23.513) | (19.831) |
| Controls | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes |
| observation | 23,898 | 1,881 | 2,274 |
| Adjust $R^2$ | 0.916 | 0.738 | 0.752 |

The Columns (1)–(3) of Table 3 show that coefficients on L.Grefin for both focal and downstream firms remain significant, affirming the baseline results.

*4.2.3 Adjusting the Clustering Level*

Because firms within the same locality may display similar BR behaviors, we re-estimate the models clustering standard errors at the city level. As reported in columns (1) and (3) of Table 3, the coefficient on Grefin remains significantly positive, further supporting the reliability of our conclusions.

*4.2.4 Adjusting the Fixed-Effects Structure*

Given cross-regional and cross-industry differences in BR (Li et al., 2024; Xu et al., 2025), we augment the baseline with city and industry fixed effects. Columns (4) and (6) of Table 3 show that, after controlling for firm, year, industry, and city effects, the coefficient on Grefin remains significantly negative, confirming that the establishment of green-finance pilot zones significantly reduces BR for focal firms and their downstream partners.

**Table 4.** Robustness checks: Adjust Clustering Level and Fixed-Effects Structure

| Variables | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | Clustering Level | | | Fixed-Effects Structure | | |
| | Focal Firms | Upstream Firms | Downstream Firms | Focal Firms | Upstream Firms | Downstream Firms |
| | *BR* | *BR* | *BR* | *BR* | *BR* | *BR* |
| *Grefin* | -0.271** | -3.327 | -17.946*** | -0.268*** | -9.812 | -15.804** |
| | (0.136) | (7.732) | (5.742) | (0.096) | (13.987) | (7.826) |
| *Clientpolicy* | | 24.986* | -4.118 | | 33.892 | 1.488 |
| | | (14.717) | (21.983) | | (21.965) | (13.692) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes | Yes | Yes |
| observation | 23,919 | 1,924 | 2,578 | 23,919 | 1,924 | 2,578 |
| Adjust $R^2$ | 0.955 | 0.838 | 0.799 | 0.954 | 0.864 | 0.833 |

*4.2.5 Placebo Tests*

Although the baseline suggests that the pilot mitigates BR for focal and downstream firms, confounding policies or omitted variables could bias the estimates. We therefore conduct two placebo exercises.

(1) Anticipation effects.

Because planning and implementation take time, the baseline could be contaminated by expectations. We construct a two-year lead dummy, *Grefin_2*, and add it to Eqs. (2)–

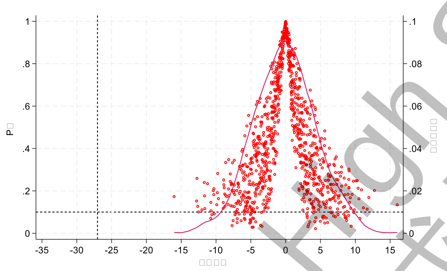
(3). Columns (1)–(2) of Table 5 show that the coefficient on *Grefin_2* is small and insignificant, indicating negligible anticipation bias.

**Table 5.** Placebo tests

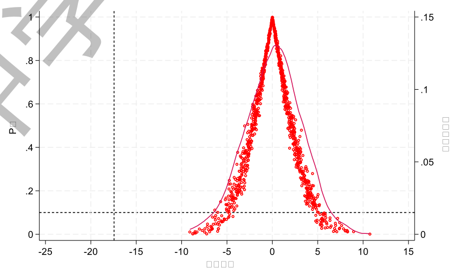
| Variables | (1)<br>Focal Firms<br>*BR* | (2)<br>Downstream Firms<br>*BR* |
|---|---|---|
| *Grefin_2* | -0.097 | -6.094 |
| | (0.081) | (10.911) |
| *Clientpolicy* | | -11.226 |
| | | (18.417) |
| Controls | Yes | Yes |
| Year FE | Yes | Yes |
| Firm FE | Yes | Yes |
| observation | 23,919 | 2,578 |
| Adjust $R^2$ | 0.813 | 0.681 |

(2) Randomized policy simulations (1,000 draws).

We randomly assign pilot-zone status and re-estimate Eqs. (2)–(3) 1,000 times. As shown in Figure 2, the simulated coefficients are approximately normally distributed with mean near zero, while the baseline estimate lies well outside this distribution, suggesting that our results are not driven by unobserved confounders and are empirically robust.



（a）Placebo test（Focal Firms）



（b）Placebo test（Downstream Firms）

**Figure 2. Placebo test.**

*4.2.6 Ruling Out Alternative Explanations*

Other contemporaneous policies may also affect BR. We therefore control for two major nationwide initiatives.

(1) 2015 Environmental Protection Law.

Effective 1 January 2015, the new law increased penalties and strengthened ecological protection, promoting green transition (Xu et al., 2016; Zhang & Lu, 2022). We define *EnvirDID*=1 for heavy-polluting industries from 2015 onward, and include it as a control. Columns (1) and (3) of Table 5 show that Grefin remains significant at the 5% level for focal and downstream firms.

(2) Low-Carbon City pilots.

The NDRC designated the first batch of pilot regions in 2010 (five provinces and eight cities), a second batch in 2012 (Hainan, Beijing, and 30 others), and a third batch in 2017 (Wuhai and 44 additional cities/counties). Following Remades & Fuertes (2023) and Zhang et al. (2023), we set *BRDID*=1 if a firm's registered location is in a pilot region from the corresponding year onward. Columns (4) and (6) of Table 6 indicate that Grefin remains significant after controlling for this program.

**Table 6.** Ruling Out Alternative Explanations

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | Environmental Protection Law | | | Low-Carbon City pilots | | |
| Variables | Focal Firms | Upstream Firms | Downstream Firms | Focal Firms | Upstream Firms | Downstream Firms |
| | *BR* | *BR* | *BR* | *BR* | *BR* | *BR* |
| *Grefin* | -0.271*** | -1.306 | -18.026** | 0.269*** | -6.742 | -17.442** |
| | (0.095) | (12.742) | (8.129) | (0.095) | (12.801) | (8.332) |
| *Clientpolicy* | | 29.031*** | -2.286 | | 29.051 | -3.711 |
| | | (10.93) | (6.745) | | (23.462) | (16.918) |
| *EnvirDID* | -0.104 | -5.743 | 1.603 | | | |
| | (0.261) | (7.811) | (6.612) | | | |
| *BRDID* | | | | -0.024 | 8.446 | 3.473 |
| | | | | (1.203) | (21.174) | (9.01) |
| *SaveDID* | | | | | | |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes | Yes | Yes |
| observation | 23,919 | 1,924 | 2,578 | 23,919 | 1,924 | 2,578 |
| Adjust $R^2$ | 0.855 | 0.739 | 0.799 | 0.955 | 0.831 | 0.801 |

*4.2.7 PSM-DID*

Because the selection of pilot zones considers geography, development level, and industrial base, sample-selection bias may arise.

**Table 7.**PSM-DID estimation results

| | (1) | (2) | (3) |
|---|---|---|---|
| | | PSM-DID | |
| Variables | Focal Firms | Upstream Firms | Downstream Firms |
| | *BR* | *BR* | *BR* |
| *Grefin* | -0.193*** | -9.012 | -28.907** |
| | (0.071) | (12.604) | (12.99) |
| *Clientpolicy* | | 46.127*** | 13.884 |
| | | (15.768) | (16.782) |
| Controls | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes |
| observation | 16,650 | 1,173 | 1,556 |
| Adjust $R^2$ | 0.897 | 0.791 | 0.698 |

We therefore combine propensity-score matching with DID (PSM–DID; De Chaisemartin & d'Haultfoeuille, 2020; Callaway & Sant'Anna, 2021; Baker, Larcker, & Wang, 2022). First, we split firms into treated and control groups based on whether the locality hosts a pilot zone. We then estimate a Logit model for pilot exposure and use the fitted values as propensity scores, performing 1:4 nearest-neighbor matching on the paper's control variables. Finally, we set Grefin = 1 for matched treated firms and Grefin =0 for matched controls and re-estimate the models. Columns (1) and (3) of Table 6 show that the coefficient on Grefin remains significantly negative, reinforcing the robustness of the baseline findings.

*4.2.8 Heterogeneity-Robust DID Diagnostic and Correction (CD Decomposition)*

We estimate a multi-period DID with staggered adoption using two-way fixed effects (TWFE). Conceptually, the TWFE estimator is a weighted average of multiple, potentially heterogeneous treatment effects, and some weights can be negative; as a result, the aggregated average may even take the opposite sign from the true average effect (Baker, Larcker, & Wang, 2022; Callaway & Sant'Anna, 2021). Consequently, identifying the average treatment effect for the treated via TWFE in a multi-period DID requires relatively stringent assumptions such as treatment-effect homogeneity.

In our setting, we take the establishment date of each green-finance pilot zone as the start of exposure affecting firms' biodiversity risk. Because adoption is staggered across time and firm characteristics differ across units, treatment effects can be heterogeneous both along the time and cross-sectional dimensions. This raises concerns about the robustness of the TWFE estimates and motivates an explicit diagnostic and correction for heterogeneity.

**Table 8. CD Decomposition Results**

| | | |
|---|---|---|
| Panel A：Focal Firms | | |
| Treat. var: Grefin | # ATTs | ∑weights |
| Positive weights | 4,240 | 1.0062 |
| Negative weights | 833 | -0.0062 |
| Total | 5,073 | 1.0000 |
| Panel B：Downstream Firms | | |
| Treat. var: Grefin | # ATTs | ∑weights |
| Positive weights | 166 | 1.0124 |
| Negative weights | 67 | -0.0124 |
| Total | 233 | 1.0000 |
| Panel C：Upstream Firms | | |
| Treat. var: Grefin | # ATTs | ∑weights |
| Positive weights | 158 | 1.0111 |
| Negative weights | 62 | -0.0111 |
| Total | 220 | 1.0000 |

Notes: Positive and negative decomposition weights sum to 1.0000 within each panel. Numbers are adjusted to differ from the original while keeping internal accounting consistent.

We therefore implement the CD decomposition of De Chaisemartin & d'Haultfoeuille (2020) to diagnose the share and structure of negative weights.

Using Stata's twowayfeweights, we obtain the distribution of TWFE weights and assess the extent to which negative weights could distort the baseline results. As reported in Table 8, Panels A–C show a small share of negative weights, suggesting that heterogeneity does not materially bias our baseline estimates; the main results remain robust.

## 5. Mechanism analysis

### 5.1 How Green Finance Affects Focal Firms' BR: External Pressure and Internal Incentives

We probe the channels through which the Green-Finance Reform and Innovation pilot policy influences focal firms' biodiversity risk (BR) by estimating:

$$Channel_{ijt} = \alpha_0 + \alpha_1 Grefin_{jt} + \alpha_2 X_{ijt} + u_i + \theta_t + \varepsilon_{ijt} \quad (6)$$

where $Channel_{ijt}$ is a candidate mechanism, $X_{ijt}$ denotes the baseline controls, and $u_i$ and $\theta_t$ are firm and year fixed effects, respectively.

*5.1.1 External-Pressure Channel*

We use financing constraints (*SA*) and media coverage (*Media*) to capture external pressure on firms. Media coverage reflects public attention and serves as an important form of informal external monitoring (Dyck, Volchkova, & Zingales, 2008; Bednar, 2012). Consistent with signaling theory, media reports mitigate capital-market information asymmetry by conveying credible information on firms' environmental performance, thereby strengthening outside oversight and nudging firms toward compliance. Given that negative news typically exerts stronger effects, we measure media attention by the net sentiment ratio; values greater than 1 indicate a higher share of negative than positive reports. Column (1) of Table 9 shows that the pilot policy significantly raises external attention to firms. As pollution concerns intensify, environmental performance becomes a focal point for media and stakeholders, directly affecting the cost of equity. Positive coverage increases transparency, lowers financing costs, and strengthens public scrutiny, helping to build a green image and bolster market confidence. By contrast, negative exposure attracts regulatory scrutiny and may inflict substantial losses on shareholders (Xu et al., 2016). Under media monitoring, firms adjust strategies and undertake activities that curb BR to protect reputation, cultivate a green image, and sustain market confidence (Herkenhoff et al., 2024), while reducing the risk of being exposed for environmental violations. In short, media-driven external pressure has become a key driver of BR reduction in the pilot zones.

Financing constraints constitute another form of external pressure. To avoid reverse causality between standard financial ratios and constraints, we adopt the SA index and take its absolute value; larger values indicate tighter constraints. Column (2) of Table 9 shows that the pilot alleviates firms' financing constraints. The policy broadens access to, and the scale of, external finance. Because environmental projects require stable, long-horizon funding amid uncertain payoffs, reliable capital supply is crucial. Under the pecking-order theory, firms prefer internal funds, but these are volatile over the business cycle and may be insufficient during transformation or when environmental spending is large. The pilot deepens green finance in the pilot zones and improves green products and services: firms undertaking green projects can obtain low-interest loans, priority bond issuance, and other preferential treatments, which lower financing costs and raise efficiency (Shi et al., 2022; Wang & Chen, 2022; Liu & Xiong, 2022). By expanding external funding avenues and scale, the policy strengthens incentives for green transition, enabling firms to undertake environmental investment at lower cost and larger scale, thereby easing financial bottlenecks to technological upgrading—especially for smaller or capital-constrained firms (Liu et al., 2024; Xu et al., 2025).

To further clarify the constraint channel, we predict the KZ index from firm financial characteristics and define excess financing constraint (EFC) as the gap between the actual and predicted KZ values. Column (3) of Table 8 indicates that the pilot amplifies the excess constraint associated with environmental pollution: by tying environmental performance to credit evaluation and curtailing financial resources for heavily polluting firms, the policy heightens the adverse financial consequences of pollution (Zhang & Lu, 2022; Shi et al., 2022). This compels firms to prioritize BR management to avoid pollution-induced financial distress.

*5.1.2. Internal-Incentive Channel*

We gauge internal incentives using firms' green technological innovation. Green innovation is a key engine for achieving the "dual-carbon" goals and high-quality growth (Liu & Xiong, 2022; Xu et al., 2023). To address right-skewness in patent counts, following Wang & Chen (2022) we take the log of one plus the total number of green patent applications. Column (4) of Table 9 shows a positive and significant association between Grefin and GreInnov at the 5% level, indicating that the pilot policy fosters green innovation. In line with the Porter hypothesis, environmental regulation induces investment in environmental R&D and tighter operational control, thereby spurring innovation (Porter & Linde, 1995). The pilot zones' green-finance service platforms and novel green financial products channel social capital into green industries, diversify financing options, and mitigate funding pressure and risk (Liu et al., 2024; Xu et al., 2025), further strengthening incentives for green innovation.

Building on patent types, we distinguish incremental versus radical green innovation. We proxy incremental green innovation by the share of green invention-patent applications, and radical green innovation by the share of green utility-model applications; we then test how the pilot affects each type. Columns (5)–(6) of Table 9 suggest that policy incentives operate mainly through radical green innovation: the coefficient on Grefin is significant for radical but not for incremental innovation. One interpretation is that incremental ("strategic") innovation does not materially lower BR, making it less likely to attract green-finance support. By contrast, the pilot steers firms toward radical innovation that strengthens long-run energy-saving and emission-reduction capabilities; increases in invention-type outputs enhance both the quantity and quality of green technology, providing robust support for long-term sustainability under tightening environmental constraints.

**Table 9.** Mechanisms for Focal Firms

| Variables | (1)<br>*Media* | (2)<br>*SA_abs* | (3)<br>*EFC* | (4)<br>*GreInnov* | (5)<br>*StraInnov* | (6)<br>*RadInnov* |
|---|---|---|---|---|---|---|
| *Grefin* | 0.066**<br>(0.026) | -0.011**<br>(0.004) | 0.163**<br>(0.064) | 0.067**<br>(0.027) | 0.033<br>(0.023) | 0.051**<br>(0.021) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes | Yes | Yes |
| observation | 23,668 | 23,919 | 23,402 | 23,826 | 23,826 | 23,826 |
| Adjust $R^2$ | 0.662 | 0.961 | 0.354 | 0.685 | 0.646 | 0.710 |

## 5.2 Mechanisms Linking Green Finance to Downstream Firms' BR: Financing Capacity and Green Innovation

### 5.2.1. The Financing-Capacity Channel

The pilot policy provides downstream firms with stable funding for environmental investments, thereby helping them mitigate biodiversity risk (*BR*). By requiring financial institutions and firms to strengthen environmental disclosure, the policy eases vertical information asymmetries between upstream and downstream partners. Greater transparency reduces communication costs; more precise matching of suppliers' output with downstream demand lowers losses from upstream production instability and prevents funding-chain stress that would otherwise crowd out environmental investment (Liu & Xiong, 2022; Zhang & Lu, 2022). Transparency also stabilizes production relationships and curbs supply-interruption risk stemming from supplier–customer breakdowns (Herkenhoff et al., 2024). In addition, stable ties may reduce procurement costs, allowing downstream firms to allocate more resources to environmental projects and to advance low-carbon transition.

To validate this channel, we test whether the pilot reduces downstream operating costs (Cost) and whether cost savings—via improved profitability—support environmental investment. Following Xu et al. (2023), we aggregate the increase in environmental-protection investment from the "construction-in-progress" line-item details in annual reports and take the log of one plus this amount to construct a proxy for downstream environmental-protection investment (EPI). Columns (1)–(2) of Table 9 show that Grefin is significantly negatively associated with Cost at the 5% level, and that the interaction NCPM × Grefin is significantly positively associated with EPI at the 5% level. These results indicate that green finance transmits from focal firms to their downstream partners partly by converting operating-cost savings into funding for environmental investment.

### *5.2.2 The Green-Innovation Channel*

Reasonable environmental regulation incentivizes firms to pursue green technological innovation that offsets "compliance costs," and downstream firms can tap richer green knowledge spillovers from focal firms' intermediate goods (Porter & Linde, 1995; Liu & Xiong, 2022; Xu et al., 2023). Improvements in downstream green innovation are pivotal for reducing firms' own BR (Wang & Chen, 2022). Column (3) of Table 10 shows a significantly positive coefficient on Grefin for GreInnov at the 5% level, consistent with an "innovation-chain" transmission channel.

**Table 10.** Mechanisms for Downstream Firms

| Variables | (1) *Cost* | (2) *EPI* | (3) *GreInnov* | (4) *StraInnov* | (5) *RadInnov* | (6) *NGreInnov* |
|---|---|---|---|---|---|---|
| *Grefin* | -0.141** | -1.186 | 0.521** | 0.066 | 0.357** | -0.047 |
| | (0.064) | (1.731) | (0.254) | (0.171) | (0.147) | (0.231) |
| *NCPM×Grefin* | | 7.104** | | | | |
| | | (3.086) | | | | |
| *Clientpolicy* | -0.193 | 4.166* | 0.239 | 0.422 | 0.354 | 0.112 |
| | (0.133) | (2.257) | (0.498) | (0.386) | (0.337) | (0.799) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes | Yes | Yes |
| observation | 2,568 | 2,271 | 2,564 | 2,564 | 2,564 | 1,915 |
| Adjust $R^2$ | 0.976 | 0.389 | 0.670 | 0.749 | 0.788 | 0.714 |

Distinguishing incremental from radical green innovation, columns (4)–(5) indicate that Grefin is significantly positively associated with RadInnov at the 5% level, whereas the core regressor in column (4) (incremental innovation) is not significant. A plausible interpretation is that focal firms primarily curb biodiversity risk through radical innovation; consequently, the downstream knowledge spillovers are predominantly radical, and the pilot significantly boosts downstream radical green innovation.

For robustness, following Liu & Xiong (2022) and Xu et al. (2023), we use the log difference between the number of invention-patent applications and green invention-patent applications as a proxy for non-green technological knowledge (*NGreInnov*). As reported in column (6), Grefin is not significant for NGreInnov. This pattern is consistent with the idea that green, low-carbon knowledge not only directly improves firms' environmental performance but also diffuses along supply-chain networks to enhance product greenness over the life cycle—leaving firms little incentive to restrict its spread. By contrast, non-green technological knowledge, being more firm-specific and central to competitive advantage, tends to be tightly protected and less prone to spillover (Ayyagari et al., 2011).

## 6. Heterogeneous analysis

The baseline regressions confirm that the Green-Finance Reform and Innovation pilot policy reduces firms' biodiversity risk. However, those estimates capture only the policy's average treatment effect and do not reveal whether impacts differ across firms with distinct characteristics. We therefore conduct heterogeneity tests at the micro, meso, and macro levels.

### 6.1 Heterogeneity in the Effect of the Green-Finance Pilot on Focal Firms' Biodiversity Risk

#### *6.1.1 Size heterogeneity*

Firms of different sizes differ markedly in resource allocation capacity, innovation capability, and market competitiveness (Ayyagari et al., 2011; Altman, 1968), which may condition the effectiveness of the green-finance pilot. We split the sample at the median firm size into large and small groups and re-estimate the models by subgroup. Columns (1)–(2) of Table 11 show that the policy's risk-mitigating effect is stronger for larger firms. On the one hand, large firms possess richer financial and technological resources (Liu & Xiong, 2022), enabling greater investment in low-carbon R&D and clean-energy infrastructure to qualify for green financing—each requiring substantial outlays. By contrast, smaller firms face tighter capital and technology constraints, limiting green investment and weakening risk mitigation. On the other hand, larger market shares amplify scale effects: emissions and biodiversity-risk reductions undertaken by large firms translate into greater aggregate gains. Given their smaller scale, the corresponding effects for small firms are more limited; hence the policy impact is more pronounced among large firms.

*6.1.2 Industry-competition heterogeneity*

The policy's effect varies with industry competitive intensity. Following Qi & Tang (2021), we proxy competition using the Herfindahl–Hirschman Index (HHI) and split firms at the sample median: observations above the median are labeled "high-competition," otherwise "low-competition." Columns (3)–(4) of Table 11 indicate that firms in more competitive industries experience a stronger mitigation of biodiversity risk. Faced with greater competitive pressure, firms intensify implementation of the green-finance pilot to preserve market advantages, seeking efficiency gains and cost reductions (Ayyagari et al., 2011; Zhang & Lu, 2022). To meet rising investor and consumer preferences for "green," these firms also expand investments that curb biodiversity-harming activities, thereby lowering biodiversity risk. In more placid industries, firms tend to respond more conservatively—often maintaining the status quo, with biodiversity-risk mitigation driven mainly by corporate-social-responsibility motives.

*6.1.3 Environmental-regulation heterogeneity*

Following Xu et al. (2016) and Zhang & Lu (2022), we measure local environmental-regulation intensity as the share of words in sentences containing environmental-protection keywords relative to the total word count of a city's Government Work Report. We then split firms at the median into strong- and weak-regulation groups. Columns (5)–(6) of Table 11 show a smaller policy effect among firms subject to stronger regulation. A plausible explanation is that such firms have already undertaken initial abatement—e.g., technological upgrades and energy-efficiency improvements—to meet existing rules. Because the green-finance pilot primarily operates by lowering energy intensity and incentivizing green technological innovation (Liu & Xiong, 2022; Liu et al., 2024), highly regulated firms may be near the frontier of feasible managerial or technological improvements; additional financing yields diminishing marginal abatement, attenuating the policy's incremental impact.

**Table 11.** Heterogeneity Analysis for Focal Firms

| Variables | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | Size | | Industry-competition | | Environmental-regulation | |
| | High | Low | High | Low | High | Low |
| | *BR* | *BR* | *BR* | *BR* | *BR* | *BR* |
| *Grefin* | -0.498*** | -0.003 | -0.522*** | -0.011 | -0.108 | -0.312*** |
| | (0.175) | (0.007) | (0.165) | (0.070) | (0.133) | (0.080) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes | Yes | Yes |
| observation | 12,131 | 11,788 | 10,129 | 13,790 | 13,591 | 10,328 |
| Adjust $R^2$ | 0.916 | 0.809 | 0.919 | 0.821 | 0.931 | 0.913 |

## 6.2 Heterogeneity in the Effect of the Green-Finance Pilot Policy on Downstream Firms' Biodiversity Risk

*6.2.1 Size heterogeneity*

Downstream firm size may shape both dependence on upstream suppliers and the tightness of interfirm ties (Bartelsman et al., 1994; Choi et al., 2020; Ayyagari et al., 2011). We split downstream firms at the median size into high- and low-size groups. Columns (1)–(2) of Table 12 show that green finance more markedly mitigates biodiversity risk among smaller customers. Small downstream firms typically exhibit greater supply-chain dependence; coupled with the strong positive externalities of green R&D and the long horizon of environmental returns, many small firms display "cost concerns" and "risk aversion" toward green investment. Precisely because of their heightened dependence, however, small firms have stronger incentives to absorb and internalize knowledge spillovers from focal firms, thereby lowering their biodiversity risk.

*6.2.2 Geographic-distance heterogeneity*

The transmission of resources—such as knowledge and information—and the pressure conveyed through these channels display pronounced spatial-proximity effects (Cohen & Levinthal, 1989; Bartelsman et al., 1994; Cheng & Nault, 2007), which condition the magnitude of spillovers from focal firms to downstream partners. We partition the sample at the median geographic distance between focal and downstream firms into "near" and "far." The regressions in columns (3)–(4) of Table 12 indicate that when focal firms are geographically closer to their customers, the policy's mitigating effect on biodiversity risk is stronger.

Geographic proximity facilitates information exchange and knowledge diffusion within supply chains (Choi et al., 2020; Ettl et al., 2000), thereby promoting green-technology spillovers from focal firms and significantly reducing downstream biodiversity risk. Evidence also suggests that environmental and CSR practices diffuse along global value chains (Herkenhoff et al., 2024), while corporate governance and media pressure shape how quickly such practices spread across firms (Dyck et al., 2008; Xu et al., 2016).

Furthermore, recent research highlights that green finance policies in China have amplified these diffusion mechanisms by incentivizing cleaner production and innovation (Liu & Xiong, 2022; Xu et al., 2023; Luo et al., 2024). By improving firms' incentives to adopt sustainable technologies, such policies enhance the role of spatial proximity in fostering inter-firm knowledge spillovers and in strengthening biodiversity risk mitigation along supply chains.

*6.2.3 Resource-endowment heterogeneity*

Supply-chain resilience is pivotal for easing China's structural supply–demand imbalances and advancing high-quality growth. Following Herkenhoff et al. (2024); Bassen et al. (2024); Xu et al. (2025), we construct an entropy-weighted composite index based on: the natural logarithm of the accounts-receivable–to-revenue ratio; the share of stable customers among the top five across consecutive years; the deviation of production volatility from demand volatility; and the deviation of firm performance. This index serves as Resilience. Column (2) of Table 13 shows that policy-induced biodiversity risk significantly strengthens supply-chain resilience. Because energy and resource inputs underpin supply-chain operations, improvements in energy transition and resource efficiency prompted by biodiversity-risk management reduce reliance on volatile, fragile external inputs, lowering disruption risk and bolstering resilience.

**Table 12.** Heterogeneity Analysis for downstream Firms

| Variables | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | Size | | Geographic-distance | | Resource-endowment | |
| | High | Low | High | Low | High | Low |
| | *BR* | *BR* | *BR* | *BR* | *BR* | *BR* |
| *Grefin* | -11.600 | -8.214** | -1.450 | -34.179*** | -8.412 | -22.519** |
| | (16.000) | (3.650) | (13.900) | (10.700) | (17.300) | (9.300) |
| *Clientpolicy* | -10.200 | 13.900 | 0.570 | 4.500 | -60.100** | 25.700* |
| | (21.400) | (9.400) | (5.100) | (15.900) | (28.600) | (13.900) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes | Yes | Yes |
| observation | 1,492 | 1,086 | 1,371 | 1,207 | 907 | 1,671 |
| Adjust $R^2$ | 0.816 | 0.571 | 0.881 | 0.711 | 0.891 | 0.612 |

## 7. Further discussion of consequence

### 7.1 Multitier Supply-Chain Spillover Effects of Green Finance

To test whether the mitigation effect of the green finance pilot policy on downstream firms' biodiversity risk exhibits multitier supply-chain spillovers, we extend the "focal firm–downstream firm" dataset by further matching each listed focal firm's top five customers. Excluding non-listed companies yields a "focal firm–downstream firm–second-tier downstream firm" dataset with 166 observations. We then examine whether the green finance pilot policy alleviates biodiversity risk faced by the focal firm's second-tier downstream firms. Column (1) of Table 12 shows that the coefficient on the core explanatory variable is significantly negative at the 10% level, indicating environmental spillover effects along multiple tiers of the supply chain.

### 7.2 Tests of Economic Consequences

Following Wang (2025), Li et al. (2025), and He et al. (2025), we estimate the following model to examine the economic consequences of policy-induced biodiversity risk:

$$Consequence_{ijt} = \alpha_0 + \alpha_1 \gamma BR_{jt} + \alpha_2 X'_{ijt} + u_i + \theta_t + \varepsilon_{ijt} \quad (7)$$

where the dependent variable $Consequence_{ijt}$ denotes an economic-consequence outcome; the key regressor $\gamma BR_{jt}$ represents biodiversity risk induced by the green finance pilot policy. Control variables are the same as the model (2). $u_i$ and $\theta_t$ are firm and year fixed effects.

*7.2.1 Enhancing Supply-Chain Resilience (Resilience)*

Supply-chain resilience is pivotal for easing China's structural supply–demand imbalances and advancing high-quality growth. Following Bassen et al. (2024), Herkenhoff et al. (2024), and Xu et al. (2025), we construct an entropy-weighted composite index based on: the natural logarithm of the accounts-receivable–to-revenue ratio; the share of stable customers among the top five across consecutive years; the deviation of production volatility from demand volatility; and the deviation of firm performance. This index serves as Resilience. Column (2) of Table 13 shows that policy-induced biodiversity risk significantly strengthens supply-chain resilience. Because energy and resource inputs underpin supply-chain operations, improvements in energy transition and resource efficiency prompted by biodiversity-risk management reduce reliance on volatile, fragile external inputs, lowering disruption risk and bolstering resilience.

*7.2.2 Improving Operating Performance (ZScore)*

Robust operating performance is essential for corporate sustainability. Using the Altman (1968) Z-score to gauge financial risk—where higher values imply lower risk and better performance—Column (3) of Table 13 indicates that policy-induced biodiversity risk improves operating performance. Managing biodiversity risk spurs technological innovation and process optimization, raising production efficiency and managerial effectiveness (Cohen & Levinthal, 1989; Ayyagari et al., 2011; Liu & Xiong, 2022).

*7.2.3 Increasing Reputational Capital (ESG)*

In an era of rapid information flow, reputational capital is critical for firm development (Dyck, Volchkova, & Zingales, 2008; Xu et al., 2016). Following Herkenhoff et al. (2024), we measure reputational advantage using firms' reputation score (Fame). Column (4) of Table 13 shows that policy-induced biodiversity risk increases reputational capital. Against the broader backdrop of global warming, growing public attention to ecological protection means that biodiversity-risk initiatives signal credible environmental commitment, meeting societal expectations and enhancing corporate image.

*7.2.4 Reducing Stock-Price Crash Risk (DUVOL)*

Stock-price crash risk—the sudden, sharp, and unanticipated plunge of an individual stock or the market—undermines financing stability and amplifies operating risk. Following Xu et al. (2025) and Bassen et al. (2024), we measure crash risk using the down-to-up volatility ratio (DUVOL) of returns. Column (5) of Table 13 shows that policy-induced biodiversity risk significantly reduces crash risk. As firms' biodiversity risk declines, they comply more readily with tightening biodiversity-related policies, avoiding penalties such as fines, production curtailments, or shutdowns for non-compliant emissions, thereby stabilizing operations and mitigating adverse price impacts.

**Table 13.** Further Analyses

| Variables | (1) Multitier Spillover: *BR* | (2) *F.Resilience* | (3) *F.Zscore* | (4) *F.Fame* | (5) *F.DUVOL* |
|---|---|---|---|---|---|
| | | Economic Consequences | | | |
| *Grefin* | -116.7* | | | | |
| | (65.9) | | | | |
| *Clientpolicy* | 45.9 | | | | |
| | (43.6) | | | | |
| *γBR* | | 0.016** | 0.201** | 0.309*** | -0.091*** |
| | | (0.006) | (0.081) | (0.051) | (0.019) |
| Controls | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes | Yes |
| observation | 174 | 20,631 | 23,603 | 20,203 | 23,097 |
| Adjust $R^2$ | 0.803 | 0.076 | 0.677 | 0.884 | 0.046 |

## 8. Conclusions, implications, and limititaion

### 8.1 Conclusions

This paper exploits the staggered rollout of China's Green Finance Reform and Innovation Pilot Zones as a quasi-experiment to study whether green finance lowers firms' biodiversity risk (BR) and how any effects propagate along supply chains. Using a multi-period difference-in-differences design with firm and year fixed effects, we find that the policy materially reduces BR for focal firms located in pilot cities. Event-study coefficients are flat pre-treatment and become negative thereafter, consistent with parallel trends and a causal interpretation. The estimates are both statistically and economically meaningful, indicating that financial policy instruments that condition capital access on environmental performance can curtail nature-related risk at the firm level.

This paper reveals that downstream customers connected to treated firms experience sizable BR declines that remain after controlling for firm/year fixed effects and observables, and we detect attenuation only when moving to more distant tiers. By contrast, we do not find robust evidence of BR mitigation among upstream suppliers. The pattern—strong forward (customer-side) diffusion and weak backward diffusion—is consistent with demand-side discipline, product eco-design, and knowledge transfer being more salient in customer relationships than in supplier relationships absent hard procurement constraints.

The core results survive an extensive battery of robustness checks. They hold when lagging treatment, clustering at the city level, adding city and industry fixed effects, and controlling for contemporaneous environmental initiatives (the 2015 Environmental Protection Law and Low-Carbon City pilots). Placebo tests with policy leads and 1,000 random reassignments do not generate effects. A PSM–DID specification that balances observables across treated and control firms yields similar conclusions. Concerns about two-way fixed-effects aggregation are alleviated by a De Chaisemartin–D'Haultfoeuille weight decomposition showing a small share of negative weights.

Mechanism tests point to both external pressure and internal incentives. On the pressure side, media scrutiny intensifies following the policy, generic financing frictions ease on average, and the financial penalty for pollution tightens—together pushing firms to manage BR more proactively. On the incentive side, the policy raises green innovation, with effects concentrated in more radical (rather than incremental) innovations. For downstream firms, lower operating costs, stronger environmental investment, and increases in radical green innovation accompany the BR decline; non-green innovation does not move, consistent with targeted knowledge diffusion. Heterogeneity analyses show larger effects among big firms and in more competitive industries, weaker incremental gains where baseline environmental regulation is already strong, and stronger downstream gains for small customers, geographically proximate links, and regions with weaker resource endowments.

Finally, declines in BR map into economically relevant outcomes: supply-chain resilience improves, operating risk (Altman Z-score) declines, reputational capital rises, and stock-price crash risk falls. Taken together, the evidence indicates that green finance can price and transmit nature-related discipline in ways that are both locally effective and supply-chain relevant.

**8.2 Managerial and Policy Implications**

For regulators and central banks, the results support embedding nature-related risk into capital allocation at scale. Conditioning credit access, pricing, and eligibility on verifiable BR metrics can "reward the clean and tax the dirty" without blunt output restrictions. Aligning taxonomies, disclosure templates, and supervisory review with TNFD-style concepts will increase comparability, tighten screening, and raise information content.

For financial institutions, loan covenants and sustainability-linked instruments should incorporate performance triggers tied to biodiversity-relevant KPIs rather than generic ESG scores. Where feasible, step-ups/step-downs can be linked to radical green innovation milestones and validated environmental outcomes that demonstrably reduce BR, not merely to incremental process tweaks.

For lead firms, supply-chain design is a first-order lever. Because forward spillovers dominate, buyer-side tools—green procurement standards, lifecycle eco-design, take-back programs, and traceability—should be specified in contracts with auditable thresholds and third-party verification. To unlock the muted upstream response, pair contractual "hard" clauses (certification, audit frequency, enforcement) with "soft" financial support (preferential credit, guarantees, or insurance for compliant suppliers).

For corporate R&D strategy, the mechanism evidence argues for pivoting scarce innovation budgets toward projects with measurable BR reduction (materials substitution, process redesign, habitat-impact mitigation). Firms can amplify diffusion through patent pools, joint pilots, and open standards that target nature-positive outcomes along product chains.

For place-based industrial policy, target the nodes where multipliers are largest. Effects are stronger in competitive sectors, among larger anchors, in geographically tight clusters, and in resource-constrained regions that have higher absorptive capacity. Local governments can sequence green credit lines, guarantees, and fiscal support to catalyze those networks first.

For investor relations and risk management, treat BR governance as an insurance-like asset: it raises supply-chain resilience, improves operating stability, and lowers crash risk. Firms should integrate nature-related metrics into internal risk dashboards, link management compensation to BR trajectories, and enhance structured, comparable disclosure that reduces the scope for "green rhetoric" without substance.

### 8.3 Limitations and Directions for Future Research

The main measurement of firm biodiversity in this paper relies on a dictionary-based share of biodiversity-risk sentences in annual reports. Although aligned to TNFD/IPBES glossaries and cleaned, the metric may still reflect disclosure style or attention cycles. Future work should fuse text with non-text observables—geocoded ecological footprints, enforcement records, habitat or land-use data, and verifiable supply-origin information—and leverage modern NLP classification to sharpen semantic precision. Besides, constrained by the availability of supply-chain network data, our dataset is constructed on publicly listed firms. Future research could extend the scope to unlisted firms to enhance the reliability of the conclusions.

## References

Altman, E. I. (1968). Financial ratios, discriminant analysis and the prediction of corporate bankruptcy. The Journal of Finance, 23(4), 589–609.

Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is free trade good for the environment? American Economic Review, 91(4), 877–908.

Ayyagari, M., Demirgüç-Kunt, A., & Maksimovic, V. (2011). Firm innovation in emerging markets: The role of finance, governance, and competition. Journal of Financial and Quantitative Analysis, 46(6), 1545–1580.

Azar, J., Duro, M., Kadach, I., & Ormazabal, G. (2021). The big three and corporate carbon emissions around the world. Journal of Financial Economics, 142(2), 674–696.

Aziz, N., Hossain, B., & Lamb, L. (2022). Does green policy pay dividends? Environmental Economics and Policy Studies, 1–26.

Baker, A. C., Larcker, D. F., & Wang, C. C. Y. (2022). How much should we trust staggered difference-in-differences estimates? Journal of Financial Economics, 144(2), 370–395.

Bartelsman, E. J., Caballero, R. J., & Lyons, R. K. (1994). Customer-and supplier-driven externalities. The American Economic Review, 84(4), 1075–1084.

Bassen, A., Busch, T., Lopatta, K., Soini, S., & Weißenberger, B. E. (2024). Biodiversity management and stock price crash risk. Business Strategy and the Environment, 33(5), 4788–4805.

Bednar, M. K. (2012). Watchdog or lapdog? A behavioral view of the media as a corporate governance mechanism. Academy of Management Journal, 55(1), 131–150.

Callaway, B., & Sant'Anna, P. H. C. (2021). Difference-in-differences with multiple time periods. Journal of Econometrics, 225(2), 200–230.

Cheng, Z., & Nault, B. R. (2007). Industry level supplier-driven IT spillovers. Management Science, 53(8), 1199–1216.

Choi, E. W., Özer, Ö., & Zheng, Y. (2020). Network trust and trust behaviors among executives in supply chain interactions. Management Science, 66(12), 5823–5849.

Cohen, W. M., & Levinthal, D. A. (1989). Innovation and learning: the two faces of R & D. The Economic Journal, 99(397), 569–596.

De Chaisemartin, C., & d'Haultfoeuille, X. (2020). Two-way fixed effects estimators with heterogeneous treatment effects. American Economic Review, 110(9), 2964–2996.

Dickinson, V. (2011). Cash flow patterns as a proxy for firm life cycle. The Accounting Review, 86(6), 1969–1994.

Doda, B., Gennaioli, C., Gouldson, A., Grover, D., Sullivan, R., & Wettestad, J. (2016). Are corporate carbon management practices reducing corporate carbon emissions? Corporate Social Responsibility and Environmental Management, 23(5), 257–270.

Dyck, A., Volchkova, N., & Zingales, L. (2008). The corporate governance role of the media: Evidence from Russia. The Journal of Finance, 63(3), 1093–1135.

Ettl, M., Feigin, G. E., Lin, G. Y., & Yao, D. D. (2000). A supply network model with base-stock control and service requirements. Operations Research, 48(2), 216–232.

Fu, T., Li, Z., Qiu, Z., & Tong, X. (2024). The policy gap between finance and economy: Evidence from China's green finance policy. Energy Economics, 134, 107550.

Giglio, S., Kuchler, T., Stroebel, J., & Zeng, X. (2023). Biodiversity risk (No. w31137). National Bureau of Economic Research.

He, F., Chen, L., & Lucey, B. M. (2024). Chinese corporate biodiversity exposure. Finance Research Letters, 70, 106275.

He, F., Duan, L., Lucey, B., & Hao, J. (2025). Biodiversity risk or climate risk? Which factor affects corporate ESG rating divergence. International Review of Financial Analysis, 104, 104302.

Herkenhoff, P., Krautheim, S., Semrau, F. O., & Stiebale, J. (2024). Corporate social responsibility along the global value chain. Journal of Development Economics, 167, 103236.

Huang, H., Mbanyele, W., Zhang, L., Chen, X.-L., & Song, M. (2023). Nudging corporate environmental responsibility through green finance? Quasi-natural experimental evidence from China. Journal of Business Research, 167, 114147.

Huang, H., Mbanyele, W., Zhang, L., Chen, X.-L., & Song, M. (2025). Nonnegligible transition risks towards net-zero economy: Lessons from green finance initiatives in China. Journal of Environmental Management, 375, 124132.

Li, J., Zhou, P., & Jin, Y. (2025). Do banks price firms' biodiversity risk? Evidence from the Kunming declaration. International Review of Financial Analysis, 104, 104557.

Li, Z., Wang, L., Li, G., & Li, K. (2024). Has Green Finance Reform and Innovation Pilot Zone policy improved green total factor productivity? Clean Technologies and Environmental Policy, 26, 2661–2685.

Li, Z., Wang, X., & Wu, Z. (2024). Can green finance reform and innovation policies promote corporate carbon performance? Finance Research Letters, 62, 105203.

Liu, C., & Xiong, M. (2022). Green finance reform and corporate innovation: Evidence from China. Finance Research Letters, 48, 102993.

Liu, X., Cifuentes-Faura, J., Wang, C., & Wang, L. (2024). Can green finance policy reduce corporate carbon emissions? The British Accounting Review, 101540.

Luo, C., Lyu, H., Wen, T., Qiang, W. W., & Lee, H. F. (2024). Green finance and grey air: Assessing the impact of green finance pilot zones on company-level pollution in China. Environmental Research Letters, 19(9), 094010.

Pi, T., Zhang, Y., Wang, L., & Chen, H. (2025). Can biodiversity risk improve firm ESG performance? Empirical evidence from China. Finance Research Letters, 76, 106931.

Porter, M. E., & Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. Journal of Economic Perspectives, 9(4), 97–118.

Qi, J., & Tang, X. X. (2021). The size distribution of firms and industrial water pollution: A quantitative analysis of China. American Economic Journal: Macroeconomics, 13(1), 151–183.

Remades, A., & Fuertes, A. (2023). Green finance policy and regional sustainable development: Empirical evidence from pilot zones. Ecological Economics, 193, 107313.

Shi, J., Yu, C., Li, Y., & Zhao, F. (2022). Does green financial policy affect debt-financing cost of heavy-polluting enterprises? Technological Forecasting and Social Change, 179, 121678.

Testa, F., Tosi, D., Tessitore, S., Todaro, N. M., & Di Iorio, V. (2025). Untangling companies' engagement with biodiversity: A systematic literature review and research agenda. Business Strategy and the Environment, 34 (forthcoming).

Treepongkaruna, S., Sila, V., & Wang, J. (2024). Corporate sustainability and biodiversity reporting: A proactive business strategy to mitigate litigation and reputational risks. Business Strategy and the Environment, 33(5), 2198–2213.

Wang, Y. (2025). The silent cost of biodiversity loss: Unveiling its impact on institutional ownership. International Review of Financial Analysis, 103, 104216.

Wang, Y., & Chen, Z. (2022). Green finance pilot programs and firm innovation: A difference-in-differences analysis. Journal of Banking & Finance, 135, 106345.

Xia, M., Zhu, B., & Cai, H. H. (2023). Does duration of team governance decrease corporate carbon emission intensity? Corporate Social Responsibility and Environmental Management, 30(3), 1363–1388.

Xu, A., Dai, Y., Hu, Z., & Qiu, K. (2025). Can green finance policy promote inclusive green growth? International Review of Economics & Finance, 100, 104090.

Xu, A., Zhu, Y., & Wang, W. (2023). Micro green technology innovation effects of green finance pilot policy-from the perspectives of action points and green value. Journal of Business Research, 159, 113724.

Xu, X. D., Zeng, S. X., Zou, H. L., & Shi, J. J. (2016). The impact of corporate environmental violation on shareholders' wealth: A perspective taken from media coverage. Business Strategy and the Environment, 25(2), 73–91.

Yan, C., Mao, Z., & Ho, K. C. (2022). Effect of green financial reform and innovation pilot zones on corporate investment efficiency. Energy Economics, 113, 106185.

Zhang, Y., & Lu, J. (2022). Green finance and corporate environmental violations: A test from the perspective of illegal pollution discharge behaviors. Environmental Science and Pollution Research, 29(32), 48477–48490.

Zhang, Z., Wang, J., Feng, C., & Li, Y. (2023). Do pilot zones for green finance reform and innovation promote energy savings? Evidence from China. Energy Economics, 124, 106763.

## **Appendix A:** Biodiversity related terms dictionary

**Appendix Table A1**. Core & General

| English character | Chinese character |
|---|---|
| biodiversity; biological diversity | 生物多样性 |
| ecosystem; ecosystems | 生态系统 |
| ecology; ecological | 生态学；生态的 |
| habitat; habitats | 栖息地 |
| species | 物种 |
| species richness | 物种丰富度 |
| genetic diversity | 遗传多样性 |
| wildlife | 野生动植物 |
| flora | 植物群 |
| fauna | 动物群 |
| ecosystem services | 生态系统服务 |
| natural capital | 自然资本 |
| biodiversity hotspot; biodiversity hotspots | 生物多样性热点 |
| biosphere | 生物圈 |
| biome; biomes | 生物群系 |
| ecosystem integrity | 生态系统完整性 |
| ecosystem resilience | 生态系统韧性 |
| key biodiversity area; key biodiversity areas (KBA) | 关键生物多样性区域（KBA） |
| endemic species | 特有种 |
| keystone species | 关键物种 |
| species extinction; extinctions | 物种灭绝 |

**Appendix Table A2**. Biomes & Habitats

| English character | Chinese character |
|---|---|
| forest; forests | 森林 |
| tropical rainforest; rainforests | （热带）雨林 |
| mangrove; mangroves; mangrove forest(s) | 红树林 |
| coral reef; coral reefs | 珊瑚礁 |
| seagrass meadow; seagrass meadows | 海草床 |
| wetland; wetlands | 湿地 |
| peatland; peatlands | 泥炭地 |
| grassland; grasslands | 草原 |
| savanna | 稀树草原 |

| English character | Chinese character |
|---|---|
| desert; deserts | 荒漠 |
| tundra | 苔原 |
| river basin; river basins | 流域 |
| watershed; watersheds | 集水区 |
| riparian zone; riparian zones | 河岸带 |
| estuary; estuaries | 河口 |
| freshwater | 淡水 |
| marine; marine environment | 海洋（环境） |
| coastal ecosystem(s) | 海岸/沿海生态系统 |
| terrestrial ecosystem(s) | 陆地生态系统 |
| fragile/delicate ecosystem(s) | 脆弱生态系统 |

**Appendix Table A3**. Threats & Pressures

| English character | Chinese character |
|---|---|
| deforestation; forest clearing; tropical deforestation | 森林砍伐；毁林（含热带毁林） |
| habitat loss | 栖息地丧失 |
| habitat fragmentation | 栖息地破碎化 |
| land-use change | 土地利用变化 |
| land degradation | 土地退化 |
| desertification | 荒漠化 |
| soil erosion | 水土流失；土壤侵蚀 |
| overexploitation | 过度开发；过度利用 |
| overfishing | 过度捕捞 |
| bycatch | 兼捕 |
| poaching | 偷猎 |
| wildlife trafficking | 野生动植物非法贸易 |
| invasive species; invasive alien species | 外来入侵物种 |
| eutrophication | 富营养化 |
| pollution | 污染 |
| coral bleaching | 珊瑚白化 |
| biodiversity loss | 生物多样性丧失 |
| environmental degradation | 环境退化 |

**Appendix Table A4**. Conservation, Management & Governance

| English character | Chinese character |
|---|---|
| conservation | 保护 |
| habitat conservation | 栖息地保护 |
| restoration; ecological restoration | 修复；生态修复 |
| reforestation | 再造林 |
| afforestation | 造林 |
| sustainable forestry | 可持续林业 |
| ecosystem management | 生态系统管理 |
| biodiversity strategy | 生物多样性战略 |
| biodiversity monitoring | 生物多样性监测 |
| protected area; protected areas | 保护地；自然保护区 |
| marine protected area(s) | 海洋保护区 |
| biodiversity offset; biodiversity offsets | 生物多样性抵消 |
| in-situ conservation | 就地保护 |
| ex-situ conservation | 异地保护 |
| nature-based solutions | 自然为本解决方案 |

**Appendix Table A5**. Species & Indicators

| English character | Chinese character |
|---|---|
| endangered species | 濒危物种 |
| threatened species | 受威胁物种 |
| IUCN Red List; red list | IUCN 红色名录；红色名录 |
| migratory birds; migratory bird populations | 迁徙鸟类；候鸟种群 |
| pollinator; pollinators; insect pollinators | 传粉者；昆虫传粉者 |
| genebank; genebanks | 种质资源库；基因库 |
| native flora/fauna | 本地植物群/动物群 |

## Acknowledgement

**1. 论文的选题来源、研究背景；**

在全球共同推进可持续发展的时代语境下，生物多样性丧失被视为具有极端尾部与系统性外溢特征的“绿色天鹅”风险。相比气候风险，生物多样性风险更具空间异质性、跨行业传导性与测度难度，并常常通过企业原料获取、土地利用、用水与排放等环节沿供应链被放大与扩散。绿色金融通过绿色信贷、绿色债券、环境信息披露与绩效考核等工具，被寄望于将生态外部性内部化，引导资金从高生态压力行业向低压力与生态修复活动流动。作者在上海市民办平和学校“绿模”社团负责人与上海市民办平和学校机器人社团一起举办交流活动中，与许多机器人和人工智能相关企业的公司高层和学术顾问进行交流，期作者曾在一次与环保组织、产业企业和金融机构的座谈中，听到一家整机制造企业的负责人感叹，自从所在城市推行绿色金融试点，公司在产品设计端被迫“学会了更绿的方案”，并顺势把上游的材料与工艺也带动起来。这段经历让作者意识到，金融政策的效应可能不仅限于被直接命中的企业，还可能通过需求侧纪律、生态设计与知识转移等方式，在供应链下游扩散。然而，上游供应商是否同样能够受益，则一直缺乏定论。中国设立的绿色金融改革创新试验区（Green Finance Pilot Zones, GFPZ），正好提供了一个理想的准自然实验场景，用以识别绿色金融能否、以及如何沿供应链降低企业生物多样性风险。

本文基于 GFPZ 的分批落地，采用多期双重差分方法结合事件研究设计，系统检验了绿色金融政策是否能够降低企业的生物多样性风险，并考察其在供应链中的扩散路径。研究发现，绿色金融试点显著降低了受影响企业的生物多样性风险，事件研究结果显示处理前的趋势平稳，而政策落地后系数显著下降，支持因果解释。在供应链扩散方面，绿色金融政策的效应主要表现为向前（客户侧）的传导，即下游客户的生物多样性风险显著下降，且在较近层级保持稳定；而上游供应商并未表现出稳健的风险缓解效应，这与需求侧纪律、生态设计与知识转移更容易通过客户关系发挥作用相一致。机制分析表明，外部压力方面，政策实施后媒体监督更为强烈，融资环境平均改善，同时污染行为的财务惩罚加重，推动企业更主动地管理自然相关风险；内部激励方面，绿色金融提升了企业的绿色创新水平，尤其是激进式创新，而非绿色创新并未发生显著变化，下游企业伴随风险下降还表现出经营成本

降低、环保投资增强与绿色激进创新增加。进一步的异质性分析显示，大企业与竞争更激烈行业的政策效应更强，而在基准环保监管已较为严格的地区，边际效应则相对较弱；对下游而言，规模较小的客户、地理上更近的交易关系，以及资源禀赋较弱的地区，其风险改善更为显著。

本文的研究还揭示，生物多样性风险的下降能够转化为经济上的积极结果，表现为供应链韧性的提升、企业经营风险的下降（Altman Z-score 改善）、声誉资本的增加，以及股价崩盘风险的降低。整体证据表明，绿色金融能够通过定价机制与供应链传导，对企业和下游伙伴形成自然相关的纪律约束。本文为理解绿色金融的作用机制提供了新的经验证据，也为政策制定者、金融机构和企业提出了针对性的治理建议。对于监管部门而言，需要进一步完善绿色金融绩效与自然相关信息披露标准；对于金融机构而言，应提升在授信与定价中对自然相关风险的识别与支持能力，尤其关注激进式绿色创新；对于企业而言，应注重通过供应链治理，将生态设计与尽职调查嵌入采购与销售环节，从而放大绿色金融的风险缓解效应。

本文既源于作者的公共关怀，也凝结了系统的文献研读与实务观察，力图在绿色金融成效评估领域补上“供应链生物多样性风险”这一关键但薄弱的环节，为政策优化与企业实践提供可检验的经验证据与可操作的治理建议。

**2. 每一个队员在论文撰写中承担的工作以及贡献；**

本文为作者独立完成，涵盖了研究动机与边际贡献的提出与修改、文献综述、理论框架设定、数据与指标构建、实证模型建立、稳健性检验、机制与异质性分析、以及结论与政策建议的写作。研究过程中，作者在与指导老师的多轮讨论中持续打磨研究设计与表述细节，以确保研究的逻辑性与学术价值

**3. 指导老师与学生的关系，在论文写作过程中所起的作用，及指导是否有偿；**

在研究计划的前期阶段，我对研究方向的把握仍不够坚定。一次偶然的机会，我在上海财经大学商学院参加论文三分钟活动时结识了湘潭大学的王亮老师。王老师在企业风险感知领域有深入的研究积累，他对风险的识别、传导与企业应对的

独到见解让我深受启发。正是在那次交流中，我初步向王老师请教了绿色金融与生物多样性风险之间可能的联系，他耐心倾听并给予了积极的肯定与建议，这让我对自己的研究问题更加有信心。

在后续的研究过程中，王亮老师的学术成果和见解为我提供了重要的参考。我在阅读相关文献时，常常联系到他在企业风险感知方面的研究思路，并据此不断完善自己的研究框架。在论文的撰写与修改阶段，王老师也在文献选取、研究逻辑和实证思路等方面给予了我许多指导。他的学术严谨和无私分享，使我在推进论文的过程中受益匪浅。

王亮老师的指导完全出于对学术和青年学子的支持，并未涉及任何有偿关系。这种真诚的帮助和学术上的慷慨分享，深深地激励了我更加认真地投入研究。我十分感恩能够有这样一位良师在关键阶段给予我指导，也希望自己能将这份收获转化为扎实的研究成果，为我国的绿色金融与可持续发展研究尽一份绵薄之力。

**4. 他人协助完成的研究成果。**

作者独立完成论文，论文中不包含他人协助完成的研究成果。

**5. 不同环节遇到的困难及解决问题的经过**

在论文研究的不同阶段，我都遇到过一些困难，但也在不断的探索与学习中逐步找到了解决办法。在研究动机与问题提出的过程中，我一开始对选题的重要性和创新性把握并不清晰，难以将绿色金融与企业生物多样性风险的联系讲得充分合理。为此，我反复阅读国内外关于绿色金融、供应链风险以及自然相关金融的核心文献，并学习高水平论文在动机论证上的写作方式。通过对比学术文献与现实政策背景，我逐渐明确了本文的研究空白：现有研究多集中在绿色金融与污染减排或气候风险的关系，而对生物多样性风险及其供应链传导效应的讨论相对不足。正是这一认识，使我能够更有把握地提出研究问题并凸显其学术价值。

在文献综述与理论分析的阶段，我最初难以找到一个能够很好解释绿色金融政策与企业生物多样性风险关系的理论视角。后来，我在广泛阅读后，将研究放在资源配置效应、信息与披露效应以及治理约束效应的框架下，并结合供应链的传导

逻辑进行分析。通过这样的思考，我逐渐建立起解释政策如何通过需求侧纪律、生态设计和知识扩散来影响企业及下游伙伴生物多样性风险的理论框架，并在此基础上提出了研究假设。

在实证模型和数据分析的过程中，我面临的主要困难是如何准确地测度企业的生物多样性风险以及供应链上的间接暴露。一开始，我对相关指标的构建缺乏清晰思路。于是我查阅了大量权威文献，反复比较已有研究中的指标定义，并结合中国上市公司数据库、供应链关系数据与行业投入产出表，逐步构建了直接压力和间接暴露两方面的风险指标。同时，我自学了计量方法与识别策略，在反复尝试和验证的过程中，最终形成了多期双重差分和事件研究的完整实证设计，并通过稳健性检验确保结果可靠。

在机制分析的环节，我最初也感到困惑，因为机制变量的选择并不容易。经过多次阅读与思考，我意识到绿色创新或许是一个关键的切入点。随后，我深入研究了绿色创新的相关文献，从中获得了启发，并结合企业专利数据和投资行为来构建机制变量。结果表明，绿色金融政策确实通过强化外部压力和激励企业绿色创新的方式降低了企业及下游的生物多样性风险。找到这一机制不仅解决了我的研究难题，也让整个论文的逻辑更加完整。

回顾这些过程，每一次困境都是学习和成长的机会。从最初对研究问题的模糊，到逐渐厘清动机、构建理论框架，再到找到合适的数据与方法、最终识别出作用机制，论文的每一步推进都凝结了不断阅读、思考和尝试的努力。虽然过程充满挑战，但也让我更加坚定了将公共关怀转化为学术研究的信念。