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# The role of industry–finance cooperation pilot policy in green innovation: evidence from Chinese firms

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**Introduction:** Under China's dual carbon goals, whether the Industry-Finance Cooperation Pilot Policy (IFCPP) improves both quantity and quality of corporate green innovation remains unresolved.
**Methods:** Taking the IFCPP as a quasi-natural experiment, we use panel data of Chinese A-share listed firms (2012–2023) and the staggered DID method, measuring innovation quantity by green invention patent applications and quality by citations.
**Results:** Results show that the IFCPP significantly boosts both the quantity and quality of green innovation, with a stronger effect on quality. The policy functions through dual pathways: external signal transmission and expectation stabilization, and internal resource allocation and innovation accumulation, with internal channels being more prominent. Interaction analyses indicate that R&D investment hedges external uncertainty, financing constraint alleviation depends on external stability, and ESG performance strengthens internal drivers. Heterogeneity analysis reveals that quality improvement is more significant for non-SOEs, manufacturing firms, and heavily polluting industries.
**Discussion:** Policy-induced green innovation enhances firm market value and drives regional economic growth via spillover effects. This study demonstrates that industry-finance cooperation facilitates the transformation of innovation from "quantity-pursuing" to "quality-valuing," supporting the green and low-carbon transition.

KEYWORDS
**corporate financing constraints, corporate green innovation, environmental social and governance performance, industry finance cooperation pilot policy, the staggered DID**

## 1 Introduction

Against the dual backdrop of global climate governance entering a critical stage and China's "dual carbon" goals (carbon peaking and carbon neutrality) advancing in depth, green innovation has become a key engine for reconciling economic growth with ecological protection and for promoting the high-end upgrading of the industrial structure. As the world's largest manufacturing country, China's industrial sector accounts for more than 70% of national carbon emissions, so its green and low-carbon transformation is crucial not only for achieving China's own high-quality development but also for shaping the global climate governance landscape (Zhang and Zhang, 2025). Within this context, the Industry-Finance Cooperation Pilot Policy (IFCPP) establishes an important institutional arrangement that links financial resources with industrial upgrading and provides a distinctive setting in which to observe how finance can stimulate corporate green innovation. By building a collaborative mechanism among governments, enterprises and financial institutions, the IFCPP uses policy guidance for green credit, risk-sharing support and information-sharing platforms to steer financial resources toward green innovation.

In 2016, the Ministry of Industry and Information Technology (MIIT) and other ministries launched the first batch of 37 IFCPP, with the second batch of 51 cities (including 18 extended pilots) expanding coverage in 2020 to direct financial resources toward industrial green development. Most existing studies focus on green financial reforms since 2012, such as the Green Credit Guidelines and green finance pilots. These policies target enterprises' capital chains by raising credit thresholds to restrict high-pollution industries and drive innovation (Zheng et al., 2025). However, a critical limitation is the reluctance of financial institutions to lend for long-cycle, high-quality green innovation due to risk aversion, lacking tripartite collaboration between government, finance, and enterprises and insufficient targeting for industrial green transition. Distinctively, IFCPP builds a collaborative system of "government-led platforms, financial risk compensation, and enterprise information transparency," precisely aligning the innovation needs of industrial chains. A representative example is the city of Yibin in China's Sichuan province: local authorities adopted a 3:3:4 risk-sharing mechanism among finance, banks, and guarantee institutions, launching customized products like "tech innovation loans" to support leading enterprises, driving green loan balances to 52.604 billion yuan with a year-on-year growth of 33.8%.[1] It is therefore of substantial practical and international relevance to systematically evaluate how this policy affects both the "quality" and the "quantity"of corporate green innovation.

Guided by this policy background, we ask two main research questions. First, does the IFCPP significantly influence the quantity and the quality of corporate green innovation? Second, through which channels does the policy affect firms' green innovation behaviour? To answer these questions, we construct a panel of Chinese A-share listed firms from 2012 to 2023, treat the rollout of the two batches of IFCPP cities as a quasi-natural experiment and employ a staggered difference-in-differences (DID) model to identify the policy's causal impact. We further use a mediation analysis framework to examine the transmission mechanisms and provide more fine-grained empirical evidence for policy evaluation.

# 2 Literature review

## 2.1 Industry-finance cooperation

Industry-finance cooperation differs from traditional financial investment by relying on capital cooperation without equity participation or personnel control. Under the guidance of government policy and through specialized policy platforms, information asymmetry is reduced between green enterprises and banks, thus mutually reinforcing industrial and financial resource capability. By avoiding the unbounded integration of industry and finance, it helps mitigate potential negative externalities such as systemic risk and market monopoly and instead focuses on building an industrial–financial ecosystem in which policy guidance and market operations interact positively. In China, industry-finance cooperation has become an important institutional instrument for promoting coordinated development between the real economy and the financial sector (Xu et al., 2025; Chen and Xiao, 2025; Zhang et al., 2025; Zhu et al., 2025; Wang and Zhang, 2025).

The theoretical foundations of industry-finance cooperation can be discussed along three dimensions. From the perspective of information transmission, it builds on relationship banking theory, which emphasizes that financial institutions accumulate soft information about firms through long-term interactions, thereby alleviating information asymmetries and collateral constraints faced by small and medium-sized enterprises and innovation projects (Boot, 2000). The IFCPP reinforces this information transmission mechanism by establishing government-led bank–firm matching platforms that reduce adverse selection in financial institutions' lending to green projects (Tirole, 2012).

From the perspective of cooperation incentives, resource dependence theory provides the internal logic for industry-finance cooperation. Pfeffer and Salancik (2015) argue that the survival and development of organizations depend on access to critical external resources. For enterprises, the high investment intensity and long payback periods of green innovation make them strongly dependent on long-term credit and equity financing. For financial institutions, the growth potential and policy dividends of green industries create strong demand for high-quality green projects. This mutual dependence constitutes the core motivation for industry-finance cooperation, and the IFCPP reduces the cost of resource acquisition for both sides and strengthens their willingness to cooperate.

From the perspective of institutional guarantees, North (1990) institutional economics framework stresses that formal institutions shape the behaviour of economic agents by influencing transaction costs and incentive mechanisms. As a typical formal institution, the IFCPP clarifies the rights and responsibilities of governments (policy formulation and supervision), enterprises (green innovation entities) and financial institutions (capital providers), standardizes cooperation procedures and risk-sharing arrangements and provides institutional support for the sustainability of industry-finance cooperation.

On the empirical side, many studies have examined its policy effects since the MIIT of China introduced the IFCPP in 2016. Zhang et al. (2025) take the IFCPP as an exogenous shock and find that it significantly reduces firms' explicit financial asset holdings, while it does not significantly reduce implicit financial assets related to shadow banking. Zhu et al. (2025) show that the IFCPP significantly improves firms' total factor productivity (TFP), not simply by increasing R&D expenditure but by enhancing resource allocation through lower internal costs and more efficient investment, highlighting the policy's role in improving firm efficiency. Wang and Zhang (2025) extend the analysis to the city level using data on 284 Chinese cities from 2012 to 2021 and find

1 Please refer to https://crpt.miit.gov.cn/#/new-detail?id=962452486503796736 for relevant case.

that the IFCPP not only significantly promotes local low-carbon transformation but also generates pronounced spatial spillovers, fostering low-carbon development in geographically and economically connected neighbouring cities.

## 2.2 Corporate green innovation

Corporate green innovation has become one of the core channels through which a win-win situation between environmental protection and economic growth is sought. Thus, it has emerged as an area of substantial interest from the academic community. Most of the previous literature discusses its drivers and constraints, depending on three dimensions: external policy incentives, internal corporate governance, and financial support.

From the perspective of external policies, the Porter Hypothesis provides a theoretical foundation for using regulation to stimulate green innovation. Porter and Linde (1995) argue that well-designed environmental regulations need not impose pure cost burdens on firms but can instead enhance competitiveness by inducing green innovation. Building on an endogenous growth framework, Acemoglu et al. (2012) show that stringent environmental regulation can redirect firms' R&D resources away from high-carbon technologies toward green technologies, thereby promoting the low-carbon transformation of industrial structures. Fischer and Newell (2008) based on evidence from U.S. renewable energy policies, find that subsidy and tax incentive schemes significantly increase firms' green innovation investment. Using data on environmental patents of U.S. listed firms in polluting industries, Berrone et al. (2013) document that institutional pressure can effectively trigger innovation, especially in industries facing stronger environmental pressure. Song et al. (2018) revealed that when environmental regulations exceed the threshold level, enterprises can enhance their green technology levels by improving the quality of their employees. More recent work emphasizes policy coordination, Han and Cai (2024) show that while environmental regulation improves firms' environmental performance, the addition of green credit policies further amplifies this positive effect.

Corporate governance shapes green innovation by influencing managerial preferences and resource allocation. Aguilera et al. (2021) argue that when environmental responsibility is embedded in board decision-making and incentive systems, managers are more likely to move beyond a narrow focus on short-term financial performance and incorporate green innovation into long-term strategic planning. This view has received growing empirical support. Liu et al. (2025) find that Chinese listed firms with directors who have green-related backgrounds apply for significantly more green patents than their peers without such directors. Using Chinese data, Yousaf et al. (2022) show that board capital, including green experience, has a significant positive impact on green innovation and that firms' absorptive capacity plays a mediating role. Ruiz-Castillo et al. (2024) further show that board independence can significantly enhance corporate environmental innovation when shareholder environmental proposals receive greater visibility. At the same time, Yu et al. (2022) find that increases in corporate privatization do not necessarily improve the green innovation performance of state-owned enterprises, suggesting that ownership reform alone is not sufficient. Liang et al. (2025) find that the ESG performance of enterprises can promote green technological innovation by alleviating financing constraints, enhancing the green development awareness of management, and improving the innovation efficiency of employees.

Financing system development and innovation have typically given solid financial backing for greens to flourish. King and Levine (1993), in a cross-country study, found that the financial development of a given country is positively associated with its capability for technological innovation; thus, the more developed a country's financial system is, the more capable it is of identifying firms with high potential activities. According to He et al. (2025), green credit has significantly boosted firms' green innovation output, which works mainly through reduced financing constraints and lower financing costs. Dong and Yu (2024) also demonstrated based on Chinese industrial enterprise data that the green bond-boosting effect on innovations is most salient in industry activities. Despite this rich body of research, studies focusing on the quality of green innovation—rather than merely its quantity—and on the combined effects of different governance mechanisms remain relatively scarce. In particular, we still know little about how external environmental and financial policies, internal corporate governance and financial system development jointly shape the quality dimension of firms' green innovation. This gap provides both the theoretical basis and the research space for the mechanism analysis conducted in this study.

Existing studies have conducted extensive discussions on industry-finance cooperation and corporate green innovation, providing important theoretical foundations and methodological references for this paper. However, there are still obvious research gaps that need to be further expanded. In the field of industry-finance cooperation, scholars have confirmed its positive effects in suppressing corporate financialization, improving total factor productivity, and promoting urban low-carbon transformation. Nevertheless, most of these studies focus on the impact of policies on corporate financial behavior and macro-regional development, with insufficient attention paid to the role of green innovation, especially the lack of in-depth investigation into the quality dimension of innovation. In the field of green innovation, existing research mostly analyzes driving factors from a single dimension of external policy incentives, internal corporate governance, and financial support. Although it has verified the role of environmental regulation, board characteristics, green credit, etc., it ignores the interactive linkage logic between different mechanisms, and the analysis of heterogeneous scenarios is not detailed enough.

To address the above shortcomings, the marginal contributions of this paper are mainly reflected in three aspects. First, it refines the classification of corporate green innovation by dividing it into quantity and quality dimensions, and systematically examines the differentiated impacts of the policy on green innovation. Second, it constructs a dual-mechanism framework of "external environment optimization (signal transmission, expectation stabilization) - internal governance improvement (resource allocation, innovation accumulation)," and further investigates the interactive effects of internal and external mechanisms, revealing the complex transmission path of the policy's impact on green innovation, which makes up for the lack of analysis on the linkage logic of mechanisms in existing studies. Third, it refines the heterogeneous analysis scenarios, conducts tests from multiple dimensions such as urban hierarchy, ownership nature, industry type, and pollution intensity, and extends to the economic effect analysis of micro corporate market value and macro regional GDP growth, providing more comprehensive empirical support for the precise implementation of policies.

# 3 Theoretical analysis and research hypotheses

As an external policy shock, IFCPP profoundly influences the quantitative expansion and qualitative improvement of green innovation by systematically reshaping enterprises' external institutional environment and internal resource conditions. Green innovation inherently features high investment, high risk, and a long revenue cycle, and its effective implementation highly relies on stable external expectations and continuous capital supply. The core value of IFCPP lies in breaking the coordination barriers between industry and finance. By establishing a government-bank-enterprise docking platform and strengthening information sharing and risk-sharing, it provides targeted resource support and improved institutional guarantees for green innovation. This impact is not a single direct effect but is transmitted through layers via four interrelated theoretical effects, clearly divided into two functional dimensions. The signal transmission effect and expectation stabilization effect focus on optimizing the external environment, while the resource allocation effect and innovation accumulation effect concentrate on improving internal conditions, ultimately taking effect through the following four specific mechanism paths.

First, the signal transmission effect arises from information asymmetry between industrial firms and financial institutions. Such asymmetry makes it difficult for lenders to accurately assess the technological value and environmental performance of green innovation projects, which may induce credit rationing or a *de facto* "reluctance to lend," especially for long-cycle and hard-to-value projects (Stiglitz and Weiss, 1981). By establishing a tripartite linked information sharing platform involving the government, enterprises, and financial institutions, the IFCPP regularly collects information on enterprises' green financing needs and green innovation levels, promotes the standardization and credibility of enterprises' environmental information disclosure, and realizes the regular operation of green resource matching between banks and enterprises. Essentially, this government-endorsed platform constructs a credible channel for signal transmission: the green policy orientation is effectively conveyed through this channel, and enterprises' commitments to green development are also released to the market through it. These signals not only lower the financing threshold for short-term green projects but also demonstrate enterprises' capabilities in sustained green R&D, thereby alleviating lenders' valuation concerns about long-term, high-uncertainty investments and mobilizing long-term capital to support core green technological breakthroughs. Meanwhile, to obtain green financial resources, enterprises will be more motivated to strengthen their fulfillment of environmental responsibilities, and further transmit credible signals of their sustainable development to the market through observable practical activities such as energy conservation, carbon reduction, and green production.

Second, the expectation-stabilization effect emphasizes how policy credibility and continuity can reduce fluctuations in firms' expectations about the external environment. Volatile expectations tend to postpone capital investment and substantially weaken incentives for long-horizon green innovation (Song et al., 2018). IFCPP stabilizes firms' expectations through two pathways. On the one hand, policy continuity and clear resource orientation convey a long-term governmental commitment to industrial green transformation, which can meaningfully shape firms' investment decisions by strengthening market expectations and reducing decision volatility, thus providing a more reliable expectation anchor for green innovation. On the other hand, government-led risk-compensation funds and related arrangements establish a tripartite risk-sharing system among the government, financial institutions, and enterprises. By relaxing downside risk constraints, such risk sharing not only encourages firms to expand green innovation portfolios and increase patenting activity, but also supports high-risk, high-return breakthroughs in core green technologies—thereby exerting a more pronounced effect on innovation quality.

Third, the resource allocation effect concerns the improvement of credit allocation toward green innovation in a bank-centered financial system. In China, banks, unlike venture capital investors, typically exhibit strong preferences for collateralized and lower-risk borrowers, which may result in credit being channeled toward large, asset-rich, and relatively safer sectors. This pattern of financial resource misallocation can leave many green innovation projects credit-constrained due to limited pledgeable assets and insufficient collateral (Lin et al., 2025). IFCPP addresses this constraint by enabling firms to disclose financing needs through a public platform and by deploying government guidance and risk-sharing instruments to facilitate bank–firm matching and due diligence. For example, local branches of the People's Bank of China may coordinate commercial banks to investigate firms with financing needs and formulate dedicated financing plans, which helps narrow information gaps between banks and firms. Through these mechanisms, IFCPP can improve the efficiency of resource allocation, alleviate firms' financing difficulties, and provide sufficient capital support for scaling up innovation projects and increasing green patent outputs.

Finally, the innovation accumulation effect captures the path-dependent and cumulative nature of green innovation. Continuous R&D investment constitutes a core prerequisite for technological iteration and breakthrough, as it builds learning and absorptive capacity over time. IFCPP reinforces this positive dynamic in two ways. First, by leveraging the resource allocation effect, it opens additional financing channels and injects dedicated funds into green innovation activities, thereby sustaining R&D investment. Second, governments incorporate both the quantity and quality of green innovation outcomes into policy evaluation systems to ensure that firms' innovation aligns with societal needs. Firms that meet these evaluation requirements can obtain sustained preferential policy support, such as preferential loans and interest subsidies, which further incentivizes continued R&D.

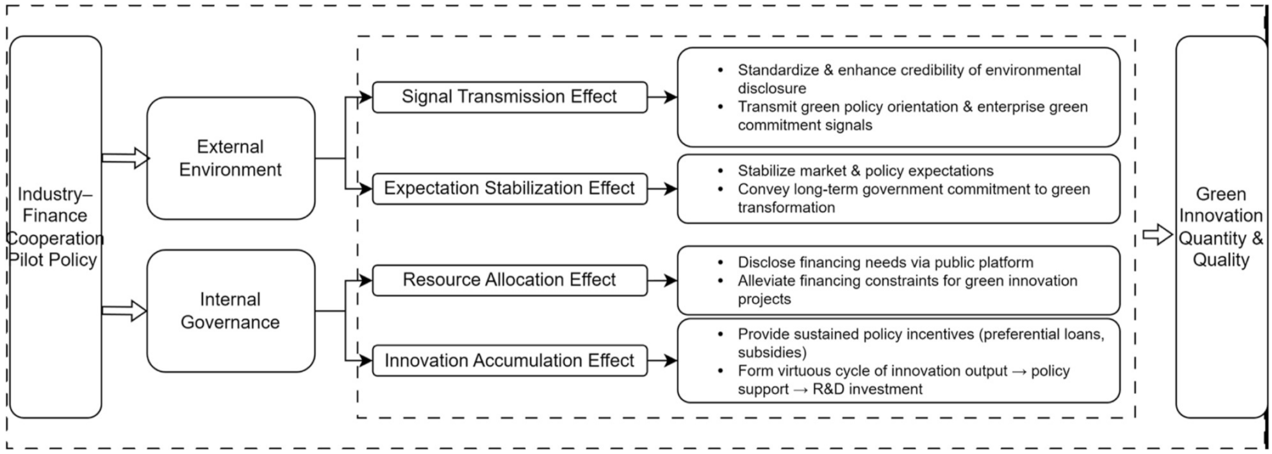


FIGURE 1
Theoretical analysis diagram.

In this way, the policy helps form a virtuous cycle of innovation outputs, policy support, and greater R&D investment, generating a cumulative advantage process akin to a Matthew effect and ultimately driving persistent expansion in innovation quantity and spiral upgrading in innovation quality. Overall, the four effects of IFCPP operate synergistically. By improving the external signal and expectation environment while strengthening internal allocation and accumulation mechanisms, the policy simultaneously relaxes key constraints on both the expansion and upgrading of green innovation, thereby providing a coherent theoretical foundation for the subsequent research hypotheses.

Figure 1 presents the theoretical mechanism of this study. On the basis of the foregoing discussion, this paper hypothesizes the following:

**Hypothesis 1:** The Industry-Finance Cooperation Pilot Policy (IFCPP) significantly improves corporate green innovation in both quantity and quality.

**Hypothesis 2:** IFCPP improves the quantity and quality of green innovation of enterprises through signal transmission, expectation stabilization, resource allocation and innovation accumulation effect.

# 4 Research design

## 4.1 Sample selection and data sources

Data from 2012 to 2023 for Chinese A-share listed firms is the initial dataset for this research. We explain the dynamic implementation of the IFCPP in terms of treatment status. The first and second batches of pilot cities were launched in 2016 and 2020, respectively, with the latter comprising cities from the first batch. Treated firms during the preperiod from 2016 to 2019 are those located in the first batch of 37 pilot cities. Treated firms between 2020 and 2023 are those in the second batch of 51 pilot cities, while firms in the 19 first-batch cities that did not enter the second batch are reclassified as controls to capture policy withdrawal. We exclude firms with insufficient time-series observations, missing key variables or ST/ST* status, and winsorize all continuous variables at the 1% level in both tails to mitigate the influence of outliers. After these steps and linear interpolation of a small number of remaining missing values, the final sample consists of 22,008 firm-year observations for 1,834 listed companies.

The list of IFCPP pilot cities was obtained from the official announcements of the Ministry of Industry and Information Technology and the Ministry of Finance. Data on corporate green innovation (citations and applications of green invention patents) were obtained from the Green Patent Database within the China Research Data Service Platform (CNRDS). Financial and corporate governance data were sourced from the China Stock Market and Accounting Research (CSMAR) database.

## 4.2 Model setting

Given the dynamic features of the IFCPP—including two pilot batches (the first in 2016 and the second in 2020) and the withdrawal of some pilot cities—the policy is implemented in a staggered fashion rather than at a single point in time. To exploit this staggered rollout, we estimate a two-way fixed-effects difference-in-differences model and treat the IFCPP as a staggered DID policy shock to identify its impact on the quantity and quality of corporate green innovation. The baseline specification is as follows (Equation 1):

$$In_{i,t} = \alpha_0 + \alpha_1 DID_{i,t} + \boldsymbol{\beta}'\mathbf{Control}_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t}, \tag{1}$$

where $i$ indexes firms and $t$ indexes years. The dependent variable $In_{i,t}$ alternately denotes two measures of corporate green innovation: $Inq_{i,t}$, capturing the quality of green innovation, and $Inn_{i,t}$, capturing the quantity of green innovation. The key explanatory variable $DID_{i,t}$ is the treatment indicator for the IFCPP, which equals 1 if firm $i$ is located in a pilot city in year $t$, and 0 otherwise. $\mathbf{Control}_{i,t}$ is a

TABLE 1 Descriptive statistics of main variables.

| Variable | N | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Inn | 22,008 | 0.686 | 1.123 | 0 | 4.970 |
| Inq | 22,008 | 0.490 | 0.987 | 0 | 4.560 |
| DID | 22,008 | 0.262 | 0.440 | 0 | 1.000 |
| Size | 22,008 | 22.660 | 1.514 | 19.900 | 28.200 |
| Lev | 22,008 | 0.460 | 0.215 | 0.057 | 0.941 |
| Roa | 22,008 | 0.032 | 0.064 | −0.238 | 0.216 |
| Roe | 22,008 | 0.051 | 0.144 | −0.738 | 0.363 |
| Cashflow | 22,008 | 0.047 | 0.068 | −0.159 | 0.244 |
| Growth | 22,008 | 0.132 | 0.393 | −0.585 | 2.470 |
| Dual | 22,008 | 0.219 | 0.413 | 0 | 1.000 |

TABLE 2 Benchmark regression results.

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Variable | Inn | Inq | Inn | Inq |
| DID | 0.075*** | 0.079*** | 0.061*** | 0.074*** |
| | (4.84) | (6.27) | (3.99) | (5.87) |
| Size | | | 0.284*** | 0.069*** |
| | | | (21.65) | (7.55) |
| Lev | | | −0.092** | 0.041* |
| | | | (-2.18) | (1.76) |
| Roa | | | −0.030 | −0.077** |
| | | | (-0.64) | (-2.23) |
| Roe | | | 0.001 | −0.011** |
| | | | (0.16) | (-2.10) |
| Cashflow | | | −0.103** | −0.027 |
| | | | (-2.15) | (-0.72) |
| Growth | | | 0.000*** | 0.000*** |
| | | | (3.94) | (3.57) |
| Dual | | | 0.041*** | 0.006 |
| | | | (2.76) | (0.48) |
| Constant | 0.674*** | 0.479*** | −5.726*** | −1.106*** |
| | (113.88) | (102.29) | (-19.56) | (-5.35) |
| Firm FE | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes |
| Observations | 22,008 | 22,008 | 22,008 | 22,008 |
| R-squared | 0.721 | 0.770 | 0.731 | 0.771 |

t values in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; The following tables are the same.

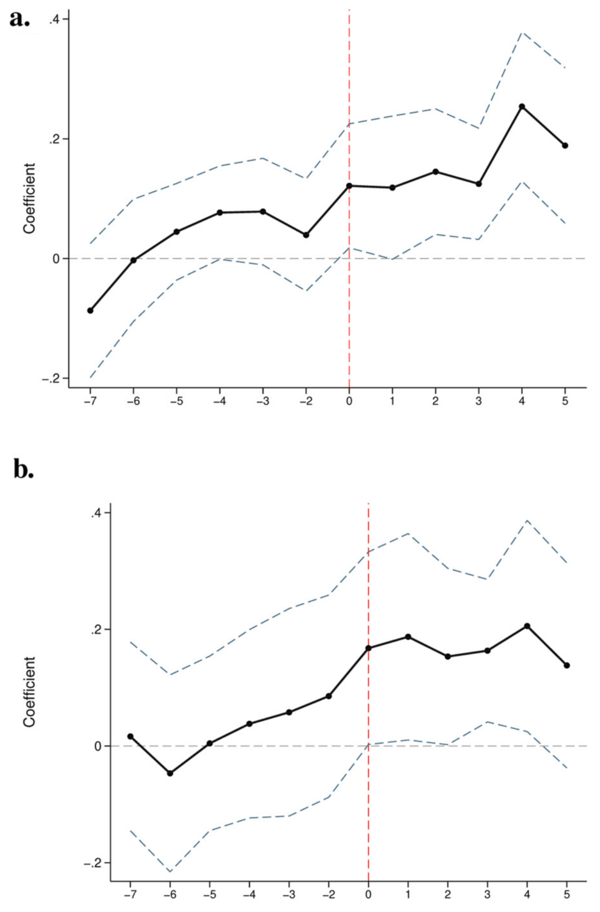


FIGURE 2
Parallel trend test for green innovation. **(a)** Parallel trend test for the quantity of green innovation. **(b)** Parallel trend test for the quality of green innovation.

vector of firm-level control variables, $\mu_i$ denotes firm fixed effects, $\gamma_t$ denotes year fixed effects and $\varepsilon_{i,t}$ is the error term.

## 4.3 Variable definitions

### 4.3.1 Dependent variables

#### 4.3.1.1 Quantity of green innovation (Inn)

Following the study by (Yu et al., 2021), we identify green innovation quantity through the yearly count of applications for green invention patents made by a firm. Thus, the indicator reflects a scale dimension of green innovation, and higher values imply a more significant outreach of activities related to green innovations.

#### 4.3.1.2 Quality of green innovation (Inq)

Following (Han and Mao, 2024), the quality of green innovation is measured by the number of citations regarding green invention patents applied for and granted within a given year. Patent citation is a conventionally accepted measure for technological value and influence in the industry; consequently, a high level infers that the green innovations of the firm possess superior technological content and application value.

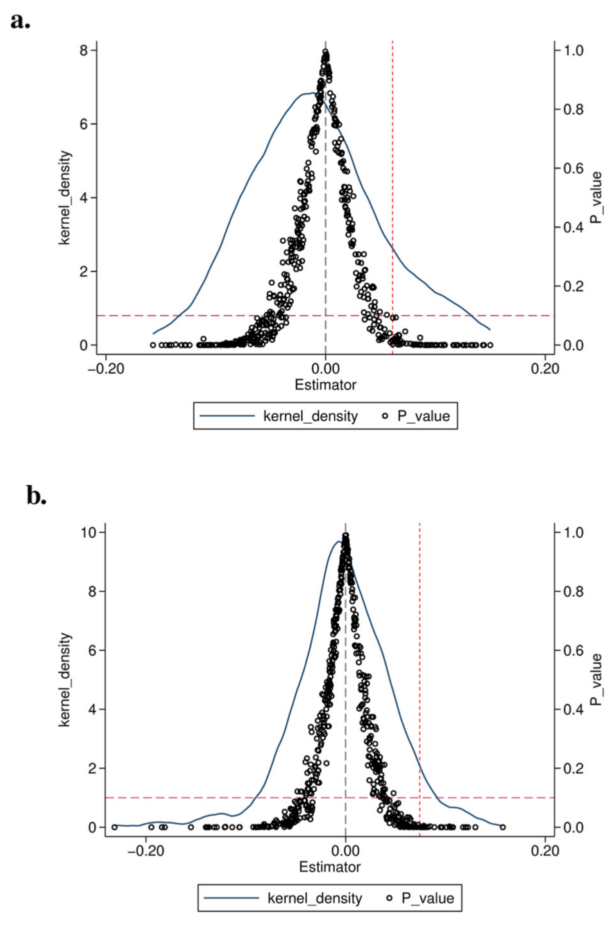


FIGURE 3
Placebo test for green innovation. **(a)** Placebo test for the quantity of green innovation. **(b)** Placebo test for the quality of green innovation.

### 4.3.2 Independent variable

The key explanatory variable is the IFCPP treatment indicator, denoted by $DID_{i,t}$, constructed from the interaction of a city-level pilot status dummy and a time dummy, formally written as $DID_{i,t} = Treat_i \times Post_t$. The variable $Treat_i$ takes on the value of 1 if firm $i$ is registered in a city that is an industry-finance cooperation pilot city and 0 otherwise. The variable $Post_t$ is defined through dynamic policy adjustment. In the first batch of 37 pilot cities in 2016, for each of them, $Post_t$ equals 1 from 2017 to 2019 thereafter; $Post_t$ will equal 0 from 2020 for the 19 first-batch cities not included in the second batch. The second batch contains 51 pilot cities in 2020; among them, 18 are extended pilot cities from the first batch. For all these cities, $Post_t$ equals 1 from 2020 to 2023; for non-pilot cities, $Post_t$ equals 0 in all years.

### 4.3.3 Control variables

To mitigate potential omitted-variable bias, we build on the corporate innovation literature and include several firm-level control variables (Zhang et al., 2025; Zhu et al., 2025; Wang and Zhang, 2025). *Firm size* (*Size*) is measured by the natural logarithm of total assets at year-end; larger firms have more resources to conduct innovations. *Leverage* (*Lev*) is defined as the ratio of total liabilities to total assets and serves as an indicator of financial leverage; high leverage may reduce R&D. *Return on equity* (*Roe*) is net profit divided by average net assets, a measure of shareholder returns that reflects how operating performance supports innovation. *Cash flow* (*Cashflow*) is net cash flow from operating activities divided by total assets, reflecting stable cash flow. It is an important guarantee for sustained R&D investment. *Revenue growth* (*Growth*) is defined as (current operating revenue−lagged operating revenue)/lagged operating revenue and indicates the firm's growth capacity. Generally, a firm will be more interested in maintaining competitive advantages through innovation. *Duality* (*Dual*) is a dummy variable that equals 1 if the positions of board chair and general manager are not separated and 0 otherwise. This variable helps explain the influence of the corporate governance structure on the effectiveness of decision-making in relation to innovation.

### 4.3.4 Descriptive statistics

Table 1 reports summary statistics for the main variables based on 22,008 firm-year observations. Regarding the dependent variables, the mean value of the quantity of green innovation (*Inn*) is 0.686, while the mean value of the quality of green innovation (*Inq*) is 0.490. The fact that the average level of innovation quality is noticeably lower than that of innovation quantity is consistent with the observation that many firms still tend to place greater emphasis on expanding the number of green patents than on achieving high-quality technological breakthroughs. In practice, some firms may file a larger number of patents with relatively low technical thresholds to satisfy compliance requirements or short-term incentives, whereas investment in core, high-value green technologies remains relatively limited on average.

The key explanatory variable (*DID*) has a mean of 0.262, which implies that about 26.2% of the firm-year observations under the sample period are exposed to the IFCPP. Other variable averages include firm size (*Size*) at 22.660 (log total assets), leverage (*Lev*) at 0.460, the return on assets (*Roa*) at 0.032, and the return on equity (*Roe*) at 0.051, which fairly represent the general financial conditions of the Chinese A-share listed firms within the sample.

## 5 Empirical results and analysis

### 5.1 Baseline regression

Table 2 presents the baseline effects of the IFCPP on the quantity and quality of corporate green innovation. Columns (1) and (2) display specifications without control variables. The coefficients on *DID* are 0.075 for *Inn* and 0.079 for *Inq*, both positive and significant at the 1 percent level, which indicates that the policy is associated with increasing the quantity and quality of green innovation. In columns (3) and (4), we further include controls for firm size, leverage, profitability, cash flow, growth, and board duality. The coefficients for *DID* remain positive and significant at the 1 percent level, with sizes of 0.061 for *Inn* and 0.074 for *Inq*. This

TABLE 3 Robustness tests.

| Variable | (1) Inn | (2) Inq | (3) Inn | (4) Inq | (5) Inn | (6) Inq | (7) Inn2 | (8) Inq2 | (9) Inn | (10) Inq |
|---|---|---|---|---|---|---|---|---|---|---|
| DID | 0.062*** | 0.076*** | 0.061* | 0.074*** | 0.071*** | 0.077*** | 0.060*** | 0.033** | 0.061*** | 0.074*** |
| | (3.92) | (5.75) | (1.81) | (2.64) | (4.62) | (6.00) | (3.90) | (2.47) | (3.99) | (5.86) |
| Big4 | | | | | | | | | −0.043 | −0.077* |
| | | | | | | | | | (-0.94) | (-1.90) |
| Mfee | | | | | | | | | −0.000 | −0.000 |
| | | | | | | | | | (-0.24) | (-0.60) |
| Fixed | | | | | | | | | −0.003 | 0.051 |
| | | | | | | | | | (-0.04) | (1.02) |
| Constant | −5.792*** | −1.104*** | −5.726*** | −1.106*** | −5.945*** | −1.169*** | −6.354*** | −1.828*** | −5.747*** | −1.178*** |
| | (-19.14) | (-5.18) | (-8.49) | (-3.26) | (-20.98) | (-5.40) | (-20.85) | (-7.94) | (-19.19) | (-5.52) |
| Control | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry FE | No | No | No | No | Yes | Yes | No | No | No | No |
| City FE | No | No | No | No | Yes | Yes | No | No | No | No |
| Observations | 21,048 | 21,048 | 22,008 | 22,008 | 22,008 | 22,008 | 22,008 | 22,008 | 22,008 | 22,008 |
| R-squared | 0.733 | 0.774 | 0.731 | 0.771 | 0.735 | 0.773 | 0.766 | 0.814 | 0.731 | 0.771 |

suggests that the estimated policy effects are robust even when firm-level controls are included, and that the IFCPP had a slightly stronger impact on the quality of green innovation than on its quantity. All in all, these results broadly support Hypothesis 1-that the IFCPP significantly enhances both the quantity and quality of corporate green innovation.

## 5.2 Robustness tests

To ensure the reliability of the baseline results, we conduct a set of robustness checks from three dimensions: a parallel trend test, placebo tests and alternative model specifications.

### 5.2.1 Parallel trend test

We first check whether the parallel trend assumption holds by estimating an event-study specification with the year preceding policy implementation as the reference period and plotting the dynamic effects of the IFCPP within a 95% confidence interval. The estimated coefficients are presented in Figure 2 for both treatment and control groups. There was no significant difference in the trend in the quantity and quality of green innovation between treated and control firms before implementing the IFCPP, which indicates that the pre-policy trends were broadly parallel. The estimated treatments have significantly increased green innovation, both in quantity and quality, in the year of policy implementation and in subsequent years. The respective changes in the control group have been insignificant. Evidence of parallel trends thus provides support for a causal interpretation of the baseline DID estimates.

### 5.2.2 Placebo test

To rule out the possibility that the estimated effects are driven by random shocks or unobserved time-varying factors, we next conduct a placebo test by simulating "pseudo policy shocks". Specifically, in each simulation we randomly select a set of "pseudo pilot cities" equal in number to the actual pilot cities, randomly assign a "pseudo policy year" between 2012 and 2023 and construct a corresponding pseudo treatment indicator. Repeating this procedure 500 times yields the empirical distribution of the placebo DID coefficients.

As shown in Figures 3a,b, the simulated coefficients are centred around zero and approximately normally distributed, with the vast majority of associated $p$-values exceeding 0.1, suggesting that the "pseudo policies" have no significant impact on green innovation. By contrast, the true policy coefficients lie far in the tails of the simulated distributions. This further confirms that the positive effects of the IFCPP on the quantity and quality of green innovation are unlikely to be driven by random chance.

### 5.2.3 Other robustness tests

We conduct further robustness checks, and the results are summarized in Table 3. Columns 1 and 2 refer to firms in the six provinces and nine cities that were included in the "Green

TABLE 4 Mechanism tests: ESG and Std5.

| Variable | (1) ESG | (2) Inn | (3) Inq | (4) Std5 | (5) Inn | (6) Inq |
|---|---|---|---|---|---|---|
| ESG | | 0.045*** | 0.015*** | | | |
| | | (7.78) | (3.17) | | | |
| Std5 | | | | | −0.009 | −0.065*** |
| | | | | | (-0.45) | (-4.31) |
| DID | 0.048** | 0.059*** | 0.074*** | −0.022*** | 0.061*** | 0.073*** |
| | (2.46) | (3.85) | (5.81) | (-4.25) | (3.97) | (5.76) |
| Constant | −1.643*** | −5.652*** | −1.082*** | −1.325*** | −5.738*** | −1.192*** |
| | (−4.16) | (−19.53) | (−5.24) | (−9.02) | (−19.74) | (−5.76) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 22,008 | 22,008 | 22,008 | 22,008 | 22,008 | 22,008 |
| R-squared | 0.513 | 0.732 | 0.771 | 0.430 | 0.731 | 0.771 |

TABLE 5 Mechanism tests: SA and Rd.

| Variable | (1) SA | (2) Inn | (3) Inq | (4) Rd | (5) Inn | (6) Inq |
|---|---|---|---|---|---|---|
| SA | | 1.624*** | 0.288*** | | | |
| | | (16.29) | (3.86) | | | |
| Rd | | | | | 2.581*** | 3.464*** |
| | | | | | (5.93) | (8.94) |
| DID | 0.012*** | 0.041*** | 0.071*** | 0.001*** | 0.058*** | 0.071*** |
| | (7.40) | (2.72) | (5.61) | (3.94) | (3.81) | (5.60) |
| Constant | −3.983*** | 0.741* | 0.043 | −0.004 | −5.715*** | −1.092*** |
| | (−34.85) | (1.75) | (0.14) | (−0.95) | (−19.58) | (−5.30) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 22,008 | 22,008 | 22,008 | 22,008 | 22,008 | 22,008 |
| R-squared | 0.966 | 0.739 | 0.772 | 0.605 | 0.731 | 0.773 |

Finance Reform and Innovation Pilot Zones" in 2017 to mitigate the potential confounding effects of this overlapping green finance policy. The *DID* coefficients retain a positive and significant value at the 1% level. This indicates that the estimated IFCPP effects are not driven by that concurrent policy. Columns 3 and 4 re-estimate the baseline model considering standard errors clustered at the city level. The coefficients on *DID* keep positive, generally significant, and their order of magnitude is similar to that of the baseline estimates, which implies that our inferences are robust to alternative clustering schemes.

Columns (5)-(6) also include industry and city fixed effects in addition to firm and year fixed effects, so they control more intensely for time-invariant industry characteristics and city-level unobservables. Results of estimated policy effects stay positive

TABLE 6 Robustness test of the mechanism effect.

| Variable | (1) ESG Inn | (2) Std5 Inn | (3) SA Inn | (4) Rd Inn | (5) ESG Inq | (6) Std5 Inq | (7) SA Inq | (8) Rd Inq |
|---|---|---|---|---|---|---|---|---|
| NIE | 0.018*** | −0.004* | 0.007** | 0.028*** | 0.013*** | −0.003* | 0.008** | 0.026*** |
| | [0.008,0.028] | [-0.008,0.001] | [0.000,0.014] | [0.012,0.044] | [0.004,0.021] | [-0.006,0.000] | [0.000,0.015] | [0.011,0.041] |
| NDE | 0.167*** | 0.187*** | 0.189*** | 0.138*** | 0.195*** | 0.210*** | 0.210*** | 0.154*** |
| | [0.106,0.227] | [0.126,0.249] | [0.123,0.255] | [0.079,0.197] | [0.139,0.252] | [0.152,0.268] | [0.157,0.264] | [0.099,0.208] |
| TE | 0.185*** | 0.184*** | 0.196*** | 0.166*** | 0.208*** | 0.207*** | 0.218*** | 0.180*** |
| | [0.123,0.247] | [0.122,0.245] | [0.128,0.264] | [0.103,0.229] | [0.150,0.266] | [0.149,0.265] | [0.162,0.273] | [0.122,0.238] |
| N | 9600 | 9600 | 9600 | 9600 | 9600 | 9600 | 9600 | 9600 |

and significant. Columns (7)-(8) employ alternative definitions of the dependent variables: the sum of green invention and utility model patent applications ($Inn2$) to proxy for the quantity of green innovation, giving the sum of citations of green invention and utility model patents ($Inq2$) to proxy for the quality of green innovation. The coefficients on $DID$ remain positive and statistically significant, which means that results are qualitatively consistent with baseline results. Finally, columns (9)-(10) control for audit quality - $Big4$ equals 1 if the firm is audited by a Big Four accounting firm - expense management efficiency, measured by $Mfee$, i.e., management expenses divided by revenue, and net fixed assets, as part of total assets. The size and significance of the $DID$ coefficients remain largely unchanged, which mitigates the concern that our results are driven by omitted-variable biases. Overall, the results from these additional analyses continue to support the view that the IFCPP has led to a significant increase in the quantity and quality of corporate green innovation.

# 6 Further tests and analysis

## 6.1 Mechanism tests

To identify and validate the mediation channels through which the IFCPP affects both the quantity and quality of corporate green innovation, we adopt a mediation analysis framework following (Heckman et al., 2013). From the two dimensions of firms' external environment and internal governance, we examine four mechanism variables: ESG, environmental uncertainty (Std5), financing constraints (SA) and R&D investment (Rd). The empirical models are specified as follows (Equation 2, 3):

$$Mech^{n}_{i,t} = \delta^{n}_{0} + \delta^{n}_{1}DID_{i,t} + \boldsymbol{\delta^{n}_{2}}\mathbf{Control}_{i,t} + \mu_i + \gamma_t + \varepsilon^{n}_{i,t}, \quad (2)$$

$$In_{i,t} = \theta_0 + \theta_1 Mech^{n}_{i,t} + \theta_2 DID_{i,t} + \boldsymbol{\theta_3}\mathbf{Control}_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t}, \quad (3)$$

where $i$ indexes firms, $t$ indexes years and $n \in \{1,2,3,4\}$ indexes the four mechanism variables. The variable $Mech^{n}_{i,t}$ denotes the value of mechanism $n$ for firm $i$ in year $t$; $In_{i,t}$ represents the quantity or quality of green innovation and corresponds to the dependent variables $Inn_{i,t}$ and $Inq_{i,t}$ defined above. The term $DID_{i,t}$ is the IFCPP treatment indicator, $\mathbf{Control}_{i,t}$ is the vector of firm-level control variables, $\mu_i$ and $\gamma_t$ denote firm and year fixed effects and $\varepsilon^{n}_{i,t}$ and $\varepsilon_{i,t}$ are error terms.

The mechanism variables are measured as follows:

- Signal Transmission Effect: Following (Fang et al., 2023; Zhang and Liu, 2023), we use the Huazheng ESG Rating Index (ESG) as the proxy. As an authoritative third-party indicator, ESG conveys both the government's green policy orientation and enterprises' environmental responsibility performance, reducing bank-enterprise information asymmetry to support green innovation financing.
- Expectation Stabilization Effect: Referring to (Ghosh and Olsen, 2009), environmental uncertainty (Std5) is measured by the five-year rolling standard deviation of enterprises' main business revenue. A higher value indicates greater external instability and worse corporate expectations; conversely, more stable expectations favor long-cycle green innovation.
- Resource Allocation Effect: Financing constraints (SA) are measured by the linear index of (Hadlock and Pierce, 2010), with higher values indicating lower constraints. The IFCPP optimizes resource allocation via a government-bank-enterprise docking platform, directing financial resources to green innovation, which is reflected by changes in the SA index.
- Innovation Accumulation Effect: R&D investment (Rd) is measured by the ratio of R&D expenditure to total assets. Green innovation is cumulative; as the IFCPP boosts its profit expectations, enterprises increase R&D input, promoting the quantity and quality upgrading of green innovation through knowledge and technology accumulation.

### 6.1.1 IFCPP and the external environment of enterprises

Columns (1)–(3) of Table 4 report the results for the ESG. In Column (1), the estimated coefficient on $DID$ in the ESG regression is 0.048 and is positive and significant at the 5% level, indicating that the IFCPP significantly improves firms'ESG performance. Columns

TABLE 7 Interaction effect test.

| Variable | (1) inn | (2) inn | (3) inn | (4) inn | (5) inq | (6) inq | (7) inq | (8) inq |
|---|---|---|---|---|---|---|---|---|
| DID | 0.058*** | 0.037** | 0.057*** | 0.039*** | 0.069*** | 0.067*** | 0.070*** | 0.070*** |
| | (3.80) | (2.49) | (3.70) | (2.62) | (5.49) | (5.32) | (5.56) | (5.56) |
| Std5 | −0.037* | −1.026*** | | | −0.079*** | −0.747*** | | |
| | (-1.92) | (-3.41) | | | (-5.37) | (-3.54) | | |
| ESG | | | 0.035*** | 0.241*** | | | 0.014*** | 0.043 |
| | | | (5.54) | (2.94) | | | (2.83) | (0.63) |
| Rd | 0.826 | | −1.508 | | 2.515*** | | 4.352*** | |
| | (1.30) | | (-0.99) | | (4.38) | | (3.28) | |
| SA | | 1.760*** | | 1.385*** | | 0.370*** | | 0.249*** |
| | | (16.70) | | (11.39) | | (4.42) | | (2.62) |
| Std5× Rd | 7.344*** | | | | 3.930** | | | |
| | (3.64) | | | | (2.22) | | | |
| Std5× SA | | −0.266*** | | | | −0.176*** | | |
| | | (-3.50) | | | | (-3.29) | | |
| ESG× Rd | | | 0.892*** | | | | −0.213 | |
| | | | (2.58) | | | | (-0.66) | |
| ESG× SA | | | | 0.053** | | | | 0.008 |
| | | | | (2.52) | | | | (0.43) |
| Constant | −5.608*** | 1.384*** | −5.553*** | −0.100 | −1.112*** | 0.345 | −1.094*** | −0.087 |
| | (-19.48) | (3.02) | (-19.05) | (-0.20) | (-5.47) | (0.98) | (-5.30) | (-0.23) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 22,008 | 22,008 | 22,008 | 22,008 | 22,008 | 22,008 | 22,008 | 22,008 |
| R-squared | 0.732 | 0.739 | 0.732 | 0.740 | 0.773 | 0.772 | 0.773 | 0.772 |

(2) and (3) incorporate ESG into the green innovation regressions. The coefficient on ESG is 0.045 for *Inn* and 0.015 for *Inq*, both significant at the 1% level, suggesting that better ESG performance is associated with higher levels of both green innovation quantity and quality. In summary, this verifies the signal transmission effect. Through the government-endorsed tripartite information sharing platform, the policy enables ESG to serve as a credible signal for enterprises to convey their green development commitments. It not only reduces bank-enterprise information asymmetry to alleviate financing constraints, but also drives enterprises to expand the number of green patents and steadily improve innovation quality in order to obtain policy resources, with quantity-oriented innovation responding more quickly in the short term.

Columns (4)–(6) of Table 4 present the mediation test results for the expectation stabilization effect, with environmental uncertainty (Std5) as the mediating variable. Column (4) shows that the coefficient of the DID term in the Std5 regression is −0.022, significant at the 1% level, indicating that the IFCPP can significantly reduce the environmental uncertainty faced by enterprises by stabilizing policy expectations and establishing a risk-sharing system. When Std5 is incorporated into the green innovation regressions in Columns (5) and (6), its coefficients are both negative, but only the impact on Inq (quality of green innovation) passes the 1% level significance test (coefficient = −0.065). This implies that the reduction of environmental uncertainty is a key mediating path through which the IFCPP promotes the improvement of green innovation quality: the stability of the external environment and policy expectations makes enterprises more willing to allocate resources to long-cycle, high-risk core technology R&D (such as green invention patents), while the marginal promoting effect on quantity-oriented innovation is relatively limited, which is consistent with the theoretical logic that the expectation stabilization effect focuses more on innovation quality.

TABLE 8 Heterogeneity analysis: city-level differences.

| Variable | (1) Inn | (2) Inq | (3) Inn | (4) Inq |
|---|---|---|---|---|
| DID | 0.043* | 0.027 | −0.013 | 0.050** |
| | (1.95) | (1.43) | (-0.51) | (2.45) |
| Constant | −3.786*** | −0.474 | −5.498*** | −0.787*** |
| | (-9.18) | (-1.59) | (-12.61) | (-2.59) |
| Controls | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes |
| Observations | 10,704 | 10,704 | 8,508 | 8,508 |
| R-squared | 0.752 | 0.786 | 0.703 | 0.761 |

TABLE 9 Heterogeneity analysis: ownership differences.

| Variable | (1) Inn | (2) Inq | (3) Inn | (4) Inq |
|---|---|---|---|---|
| DID | 0.078*** | 0.087*** | 0.031 | 0.060*** |
| | (3.50) | (4.58) | (1.50) | (3.56) |
| Constant | −5.540*** | −1.101*** | −6.052*** | −1.179*** |
| | (−11.21) | (−3.40) | (−16.54) | (−4.29) |
| Controls | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes |
| Observations | 10,272 | 10,272 | 11,736 | 11,736 |
| R-squared | 0.762 | 0.790 | 0.693 | 0.748 |

### 6.1.2 IFCPP and the internal governance of enterprises

Columns (1)–(3) of Table 5 (supplementary mediation test for the resource allocation effect) report the mediation test results for the resource allocation effect, with financing constraints (SA) as the mediating variable. In Column (1), the estimated coefficient of the DID term in the SA regression is 0.012, significantly positive at the 1% level, indicating that the IFCPP can optimize resource allocation through the government-bank-enterprise tripartite docking platform and significantly alleviate enterprises' financing constraints. After incorporating SA into the green innovation regressions in Columns (2) and (3), its coefficients on Inn (quantity of green innovation) and Inq (quality of green innovation) are 1.624 and 0.288, respectively, both passing the 1% level significance test, with a more prominent promoting effect on quantity. This verifies the mediating path through which the IFCPP promotes green innovation by alleviating financing constraints. Specifically, the policy reduces information asymmetry and guides the tilt of financial resources toward green projects, providing financial support for enterprises to expand innovation scale and increase the number of patents while laying a capital foundation for long-term investment in high-quality innovation.

Columns (4)–(6) of Table 5 (supplementary mediation test for the innovation accumulation effect) report the mediation test results for the innovation accumulation effect, with R&D investment (Rd) as the mediating variable. Column (4) shows that the coefficient of the DID term in the Rd regression is 0.001, significant at the 1% level, indicating that the IFCPP can significantly promote enterprises' R&D investment through policy incentives and resource support. After incorporating Rd into the green innovation regressions in Columns (5) and (6), its coefficients on Inn (quantity of green innovation) and Inq (quality of green innovation) are 2.581 and 3.464, respectively, both passing the 1% level significance test, with a stronger promoting effect on quality. This verifies the mediating path through which the IFCPP drives the upgrading of both the quantity and quality of green innovation by fostering the accumulation of R&D investment. Specifically, the path-dependent characteristic of green innovation underscores the core role of continuous R&D investment. By strengthening innovation incentives, the policy continuously amplifies this positive cycle effect, encouraging enterprises to increase R&D investment through positive feedback. This process not only promotes technological exploration to expand the number of patents but also enhances innovation quality through breakthroughs in basic research.

Taken together, the mediation effect test results show that all four effects have a significant impact on corporate green innovation. Among them, signal transmission and resource allocation focus more on promoting the expansion of green innovation quantity, while expectation stabilization and innovation accumulation have a more prominent role in improving innovation quality. This is consistent with the functional positioning of the four effects in the theoretical analysis, providing solid empirical support for Research Hypothesis H2.

## 6.2 Robustness test of the mechanism effect

The traditional three-step mediation test lacks a rigorous definition of causal effects that is independent of statistical modeling frameworks. Moreover, when mediating variables are confounded by post-treatment variables, the estimation of direct and indirect effects is prone to systematic biases (Acharya et al., 2016; Imai et al., 2010). To mitigate these limitations, this study supplements the traditional approach with causal mediation analysis based on the potential outcomes framework, aiming to more rigorously identify the intrinsic transmission mechanisms through which the Industry-Finance Cooperation Pilot Policy (IFCPP) affects corporate green innovation. We employs random sampling to select 800 firms (corresponding to 9,600 observations) for the test, effectively improving computational efficiency while ensuring sample representativeness. This research designates *Inn* and *Inq* as the dependent variables, and ESG, Std5, SA and Rd as mediating variables to empirically examine the transmission paths of the policy's impact on green innovation.

The results of the causal mediation analysis, presented in Table 6, indicate that: at the level of the natural direct effect (NDE), the coefficients of the direct effect are statistically significant and positive across all mediation specifications,

TABLE 10 Heterogeneity analysis: industry type differences.

| Variable | (1) Inn | (2) Inq | (3) Inn | (4) Inq |
|---|---|---|---|---|
| DID | 0.018 | 0.076*** | 0.115*** | 0.093*** |
| | (0.89) | (4.29) | (4.76) | (5.05) |
| Constant | −7.660*** | −2.401*** | −3.358*** | −0.018 |
| | (-19.39) | (-7.29) | (-7.87) | (-0.07) |
| Controls | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes |
| Observations | 13,429 | 13,429 | 8,579 | 8,579 |
| R-squared | 0.745 | 0.776 | 0.734 | 0.773 |

TABLE 11 Heterogeneity analysis: industry pollution intensity.

| Variable | (1) Inn | (2) Inq | (3) Inn | (4) Inq |
|---|---|---|---|---|
| DID | 0.081** | 0.060** | 0.035 | 0.093*** |
| | (2.28) | (2.23) | (1.46) | (4.47) |
| Constant | −6.595*** | −1.582*** | −7.941*** | −1.739*** |
| | (-11.27) | (-3.84) | (-15.96) | (-4.29) |
| Controls | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes |
| Observations | 5,578 | 5,578 | 9,966 | 9,966 |
| R-squared | 0.657 | 0.760 | 0.779 | 0.791 |

regardless of whether the dependent variable is green innovation quantity or quality—this is highly consistent with the findings derived from the benchmark regression analysis reported earlier. At the level of the natural indirect effect (NIE), improved ESG, alleviated financing constraints (SA), and increased R&D investment (Rd) all exhibit statistically significant positive mediating effects, while the mediating effect of environmental uncertainty is statistically significant and negative. This result is fully consistent with the theoretically anticipated transmission mechanisms. Collectively, these empirical findings further validate the theoretical plausibility of Hypotheses H1 and H2.

## 6.3 Interaction effect test in mechanism analysis

To further clarify the linkage logic between external and internal mechanisms, this study constructs a regression model incorporating interaction terms to identify the complementary or substitutive relationships between these two types of mechanisms. The model specification is as follows (Equation 4):

$$In_{i,t} = \beta_0 + \beta_1 DID_{i,t} + \beta_2 T_{i,t} + \beta_3 Z_{i,t} + \beta_4 T_{i,t} \times Z_{i,t} + \boldsymbol{\beta}_5 \mathbf{Control}_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t}, \quad (4)$$

Among them, the interaction term $T_{i,t} \times Z_{i,t}$ serves as the core criterion for judging the relationship between external and internal mechanisms: if $\beta_2 > 0$ and $\beta_3 > 0$ while $\beta_4 > 0$ the two variables exhibit a complementary relationship (mutual reinforcement effect); if $\beta_4 < 0$, they show a substitutive relationship (mutual weakening effect); if $\beta_2 > 0$ and $\beta_3 < 0$ while $\beta_4 > 0$, the two variables present a substitutive relationship (variable T mitigates the negative effect of variable Z); if $\beta_4 < 0$, they exhibit a complementary relationship (variable T strengthens the negative effect of variable Z).

The regression results reported in Table 7 indicate the following: First, the interaction term between environmental uncertainty (Std5) and R&D investment (Rd) is statistically significant and positive in both the green innovation quantity and quality equations. Given that a higher Std5 value indicates greater external environmental uncertainty, this positive interaction effect reveals that increased R&D investment can significantly hedge against the inhibitory effect of environmental uncertainty on green innovation, reflecting a substitutive logic whereby "internal R&D reserves mitigate external risk shocks". By increasing R&D investment to consolidate core technological foundations, enterprises reduce their dependence on external environmental stability, thereby maintaining stable green innovation output even in high-uncertainty scenarios.

Second, the interaction term between external environmental uncertainty (Std5) and financing constraints (SA) is significantly negative in both equations of the dependent variables. Considering the definition of the SA index (a higher value denotes a lower degree of financing constraints), this result confirms that the promoting effect of financing constraint alleviation on green innovation is highly dependent on the improvement of external environmental stability. If financing constraints are merely alleviated without the simultaneous optimization of the external business environment and policy implementation environment, the positive driving effect of financing constraint alleviation will be weakened or even transformed into a negative impact. Only when external environmental stability and internal capital support form a synergistic effect can they effectively empower the "dual improvement in quantity and quality" of green innovation.

In addition, the interaction terms between ESG performance and R&D investment (Rd), as well as between ESG performance and financing constraints (SA), are both significantly positive in the green innovation quantity equation, while the coefficients are positive but not statistically significant at conventional levels in the quality equation, generally exhibiting complementary effects. This finding indicates that the external trust signal from ESG performance is more effective under the IFCPP, significantly alleviating bank-enterprise information asymmetry and further strengthening the positive effects of internal R&D investment

TABLE 12 Economic consequence analysis.

| Variable | (1) Lnmc | (2) Lnmc | (3) Lgdp | (4) Lgdp |
|---|---|---|---|---|
| Treat × Post × Inn | | 0.005* | | 0.008*** |
| | | (1.71) | | (11.69) |
| Treat × Post × Inq | 0.007** | | 0.006*** | |
| | (2.36) | | (8.38) | |
| Constant | 6.404*** | 6.537*** | 18.081*** | 18.093*** |
| | (29.68) | (29.83) | (497.54) | (499.58) |
| Controls | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes |
| Observations | 22,008 | 22,008 | 19,884 | 19,884 |
| R-squared | 0.967 | 0.968 | 0.996 | 0.996 |

and financing constraint alleviation on green innovation. Moreover, this reinforcement effect is more prominent in the dimension of green innovation quantity.

## 6.4 Heterogeneity tests

To further examine how the IFCPP operates under different regional, ownership and industry contexts, we conduct a set of heterogeneity analyses. At the city level, we focus on urban administrative hierarchy and coastal status. At the firm and industry level, we divide the sample by ownership type, industry attributes and pollution intensity to explore potential heterogeneous policy effects and provide more targeted empirical references for policy implementation.

### 6.4.1 Urban heterogeneity

Table 8 catalogs our city-level heterogeneity results. Columns (1)–(2) consider administrative hierarchy. We create a dummy that equals 1 for provincial capitals and municipalities directly under the central government and 0 otherwise, and we examine policy effects for firms in these cities. The coefficient on *DID* is 0.043 for *Inn* at the 10% significance level, while that for *Inq* is 0.027, not statistically significant. This suggests that the IFCPP mainly encourages a substantial increase in *quantity* in corporate green innovation, but the quality of such innovations does not have any measure in the short term, particularly in provincial capitals and centrally administered municipalities.

Columns (3)–(4) consider geographic location by focusing on coastal cities, defined according to the *China Statistical Yearbook* as cities with a coastline. Coastal cities typically enjoy advantages in foreign trade, human capital and financial development. The estimates show that in coastal cities the coefficient on *DID* is insignificant for *Inn* (−0.013) but positive and significant for *Inq* (0.050 at the 5% level), indicating that the IFCPP in these cities is more strongly associated with improvements in the *quality* of green innovation.

These patterns are consistent with differences in local resource endowments and innovation environments. In provincial capitals and centrally administered municipalities, administrative resources are more concentrated and policy signals are stronger, so firms may respond quickly by expanding the *number* of green patents to visibly align with policy targets, while deeper, high-tech quality improvements are constrained in the short run by more limited opportunities for high-end knowledge spillovers. By contrast, coastal cities benefit from port advantages, more open trade links, richer human capital and more developed financial markets. The IFCPP therefore makes it easier for firms in these cities to acquire advanced innovation resources, absorb frontier technologies and upgrade their innovation capabilities, leading to more pronounced improvements in the *quality* of green innovation.

### 6.4.2 Property rights heterogeneity

Table 9 examines heterogeneity by ownership of the ultimate controlling shareholder by splitting the sample into state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs). Columns (1)–(2) report the results for SOEs, and Columns (3)–(4) for non-SOEs. For SOEs, the coefficients on *DID* are 0.078 for *Inn* and 0.087 for *Inq*, both positive and significant at the 1% level, indicating that the IFCPP significantly increases both the quantity and the quality of green innovation in state-owned firms. For non-SOEs, the coefficient on *DID* is insignificant for *Inn* (0.031) but positive and significant for *Inq* (0.060 at the 1% level), suggesting that the IFCPP mainly promotes improvements in the quality of green innovation among non-state-owned firms.

A plausible explanation is that SOEs undertake policy implementation responsibilities and enjoy advantages in resource endowments. Ample funding and human capital allow them not only to expand the scale of green innovation across multiple technological fields in response to policy targets, but also to invest in core technology inventions to meet social responsibility expectations and policy performance assessments (Zhou et al., 2017). By contrast, non-SOEs face tighter financing constraints and more intense market competition, and lack the policy buffers and resource redundancy available to SOEs. As a result, they are more likely to concentrate limited resources on high-value, quality-oriented green innovation in order to build differentiated competitive advantages, while the expansion of innovation quantity is relatively constrained. In essence, these findings suggest that firms with different ownership structures follow different resource allocation logics and innovation strategies: SOEs can simultaneously pursue the scale and quality of green innovation, whereas non-SOEs, under stronger survival pressure, tend to rely more on the *quality* dimension of green innovation to compete in the market.

### 6.4.3 Industry heterogeneity (manufacturing vs. non-manufacturing)

Table 10 demonstrates heterogeneity results across industry types, where firms are classified into manufacturing and non-manufacturing categories based on the 2012 *Guidelines for*

*Industry Classification of Listed Companies*. Columns (1)-(2) show the results for manufacturing firms. The coefficient on $DID$ is insignificant for *Inn* (0.018) but positive and significant at the 1% level for *Inq* (0.076), indicating that the IFCPP significantly improves the *quality* of green innovation among manufacturing firms, whereas, for the *quantity*, it does not show any significant effect. Columns (3)-(4) present the results for non-manufacturing firms. For this subsample, the coefficients on $DID$ are positive and significant at the 1% level for both *Inn* (0.115) and *Inq* (0.093), indicating the IFCPP significantly increases both the quantity and quality of green innovation in non-manufacturing sectors.

These results are consistent with differences in asset structure and innovation risk between manufacturing and non-manufacturing industries. Manufacturing sectors are typically capital-intensive, and green innovation projects often involve large, specialized fixed investments and long development cycles. Such characteristics make it more difficult for manufacturing firms to rapidly scale up the *number* of green innovation outputs in response to policy incentives, but they can still use the IFCPP to upgrade the *quality* of core technologies. By contrast, many non-manufacturing firms operate with lighter asset structures and require relatively less large-scale fixed investment for green innovation—software and service firms, for example, can iterate technologies more quickly with fewer fixed assets and lower relative project risk than heavy-asset industries. This allows non-manufacturing firms to leverage the IFCPP to simultaneously expand the scale and enhance the quality of green innovation.

### 6.4.4 Industry pollution intensity heterogeneity

Following the approach of (Li and Zeng, 2020), we further divide industrial firms into heavily polluting and clean industries. The regression outcomes are provided in Table 11, with Columns (1)-(2) covering heavily polluting industries and Columns (3)-(4) covering clean industries. The coefficients of $DID$ for heavily polluting firms are 0.081 for *Inn* and 0.060 for *Inq*; both are positive and significant at the 5% level, meaning that IFCPP significantly increases both the quantity and quality of green innovation for high-pollution industries. For clean industries, the coefficient on $DID$ is insignificant for *Inn* (0.035) but positive and significant at the 1% level for *Inq* (0.093), indicating that policy mainly promotes quality for green innovations in relatively clean industries.

These findings are consistent with differences in regulatory pressure and innovation incentives across industries. Heavily polluting industries face stricter environmental regulation and stronger public scrutiny. Through instruments such as preferential green credit and targeted technology subsidies, the IFCPP creates both compliance pressure and financing support, encouraging these firms to rapidly expand quantity-type green innovation to meet regulatory requirements and, at the same time, to invest in higher-quality green technologies to facilitate long-term transition. In clean industries, environmental pressure is relatively lower and innovation incentives are driven more by market competition than by regulatory mandates. Firms in these sectors therefore tend to focus more on quality-oriented green innovation to differentiate their products and services, resulting in more pronounced improvements in innovation quality than in quantity.

## 7 Extended analysis

To come closer to a complete appraisal of the worth of the IFCPP, we make further inquiries into its economic outcomes, asking whether policy-related gains in the quantity and quality of green innovation find reflection in enhanced firm values and regional economic growth. This shall give us the possibility of describing a more complete transmission chain from policy through innovation to economic outcomes. According to the three-dimensional difference-in-difference approach suggested by Lan et al. (2025), the triple interaction term $Treat \times Post \times In$ has been created, and the economic impacts of the policy are evaluated in terms of market value and regional economic development. The dependent variable on the firm level is the natural logarithm of market capitalization ($Lnmc$) for the listed firms, representing the firm value. The dependent variable at the regional level is the natural logarithm of GDP ($Lgdp$) in the prefecture-level city, representing regional economic development. In each specification, $In$ will take on the role of green innovation quantity ($Inn$) and quality ($Inq$).

Columns (1)–(2) of Table 12 report the results for firm market value, and Columns (3)–(4) report the results for regional GDP. At the firm level, the interaction $Treat \times Post \times Inq$ has a positive coefficient of 0.007 on *Lnmc* and is significant at the 5% level, while the coefficient on $Treat \times Post \times Inn$ is 0.005 and significant at the 10% level. This indicates that policy-induced increases in both the quantity and the quality of green innovation are associated with higher firm market value, with the effect of quality-oriented green innovation being somewhat stronger. At the regional level, both triple interaction terms are positive and significant at the 1% level: the coefficient on $Treat \times Post \times Inq$ is 0.006 and that on $Treat \times Post \times Inn$ is 0.008. These results suggest that green innovation driven by the IFCPP not only enhances firms' market value, but also, through technological spillovers and industrial upgrading, contributes to faster regional economic growth. Overall, the extended analysis highlights the dual role of the IFCPP in supporting micro-level firm value creation and macro-level high-quality economic development through its impact on the quantity and quality of corporate green innovation.

## 8 Research conclusions and policy recommendations

### 8.1 Research conclusions

This study adopts the staggere DID method and takes the Industry-Finance Cooperation Pilot Policy (IFCPP) as a quasi-natural experiment to systematically examine the impact of the IFCPP on firms' green innovation levels. The results show that the IFCPP effectively stimulates the vitality of firms' green technological innovation: it not only significantly increases the quantity of green patents, but also effectively mitigates firms' long-standing tendency to prioritize quantity over quality, thus achieving a synergistic improvement in both the quantity and quality of green innovation. Overall, the policy's effect on improving green innovation quality is significantly stronger than that on quantity, which confirms its core value in guiding firms to focus on core technological breakthroughs and optimize the innovation structure.

Mechanism tests reveal that the IFCPP synergistically boosts both the quantity and quality of firms' green innovation through four effects, namely signal transmission, expectation stabilization, resource allocation and innovation accumulation. At the level of external mechanisms, the policy sends a clear signal of green development and stabilizes firms' expectations, which not only enhances firms' market credibility and reduces information asymmetry between banks and enterprises, but also creates a stable and reliable external institutional environment for green innovation. At the level of internal mechanisms, the policy optimizes resource allocation and alleviates financing constraints for green innovation by relying on the government-bank-enterprise tripartite platform; it also forces firms to incorporate green innovation into their long-term strategies and continuously increase R&D investment to form a positive cycle, thus activating endogenous motivation for innovation. Further analysis of the interactive linkage effects of internal and external mechanisms shows that the two exhibit distinct heterogeneous characteristics in their roles. There is a substitution effect between external environmental uncertainty and R&D investment, where increased R&D investment can effectively hedge against external risk shocks; the promotional effect of financing constraint alleviation on green innovation is highly dependent on the stability of the external environment, and joint efforts of the two are required to drive the synergistic improvement in the quantity and quality of green innovation; ESG performance, as the core measure of the signal transmission effect, has a complementary effect with R&D investment and financing constraint alleviation, which can strengthen the innovation-promoting effect of internal factors by mitigating information asymmetry, and this synergistic effect is more prominent in the quantity dimension of green innovation.

Heterogeneity analysis indicates that the policy effects of the IFCPP exhibit significant scenario adaptability, with differentiated characteristics across different city types, ownership types, industries and pollution levels. In provincial capitals and municipalities directly under the central government, the policy effect is concentrated on the quantity dimension of green innovation with a relatively weak improvement in quality, showing a potential tendency of policy arbitrage characterized by prioritizing quantity over quality. Leveraging their advantages in openness, coastal cities have a more prominent effect on improving green innovation quality and are more likely to generate high-quality innovation spillovers. State-owned enterprises (SOEs) achieve significant improvements in both the quantity and quality of green innovation, while non-SOEs only see notable progress in quality, which reflects the impact of ownership nature on policy transmission efficiency. At the industry level, the policy significantly enhances the green innovation quality of manufacturing industries (with no significant change in quantity), whereas non-manufacturing industries realize dual improvements in both quantity and quality. The policy's incentive effect on green innovation is far stronger in heavily polluting industries than in cleaner ones, particularly evident in the improvement of quantity, which confirms the policy's precise empowerment of key areas for pollution control.

From the perspective of economic effects, the synergistic improvement in the quantity and quality of green innovation has been translated into tangible economic benefits. At the micro level, policy-driven green innovation significantly enhances firms' market value, achieving a positive interaction between environmental responsibility and value creation. At the macro level, prefecture-level cities covered by the policy have witnessed a notable acceleration in GDP growth rate, indicating that the IFCPP effectively facilitates high-quality regional economic development through the technology spillover and industrial upgrading effects of green innovation.

It should be noted that while exerting positive effects, the IFCPP is accompanied by potential negative risks that may weaken the effectiveness of policy outcomes. First, there is the risk of policy arbitrage and formalistic responses, which is prominently reflected in the overemphasis on quantity over quality in green innovation in provincial capitals. This may stem from local governments driving firms to conduct "quantity-focused" patent applications to meet assessment requirements, which runs counter to the orientation of high-quality innovation. Second, there is the risk of resource misallocation and concentration. SOEs are more likely to obtain policy dividends and financial resources than non-SOEs, resulting in more significant improvements in both the quantity and quality of their green innovation. This may squeeze the innovation resources and financing space of non-SOEs, especially small and medium-sized private enterprises, leading to imbalanced resource allocation. Third, there exists the risk of greenwashing. Compared with manufacturing industries that need to invest substantial R&D costs in substantive technological transformation for green innovation, non-manufacturing industries (e.g., green services and environmental consulting) can more easily package themselves through formalistic practices to obtain green credit and policy subsidies. Such "pseudo-green innovation" not only distorts policy orientation but also may disrupt the normal order of the green innovation market. In summary, the IFCPP has established a positive linkage between environmental performance and economic performance, yet it is imperative to implement targeted policies based on heterogeneous characteristics to guard against the aforementioned risks, thereby giving full play to its dual role in supporting enterprise value creation and regional economic growth.

## 8.2 Policy recommendations

Based on the above findings and anticipated risks, this paper proposes policy recommendations along three complementary dimensions: government top-level design, industry coordination, and the strengthening of firms' endogenous incentives.

First, strengthen government top-level design. A comprehensive policy framework should account for heterogeneity across regions, ownership structures, and industries while balancing innovation incentives with risk prevention. In practice, evaluation systems should shift from a sole emphasis on patent counts to quality-oriented metrics, such as citation counts of green invention patents, technology commercialization (conversion) rates, and carbon-emission reductions per patent. Third-party substantive review can be introduced, and firms engaged in low-value repetitive patenting or misleading disclosures should face credit-related penalties and restricted access to green credit. At the same time, policymakers should improve resource-balancing mechanisms to reduce allocative distortions by establishing a national coordination mechanism for industry–finance cooperation and directing risk-compensation instruments, supported by government investment funds, toward qualified green innovation projects by small and medium-sized private firms. Finally, a dynamic adjustment mechanism is needed: data-driven monitoring systems can be used to track implementation outcomes, publish annual evaluation reports, and calibrate policy instruments (e.g., subsidy intensity and approval standards) in a timely and evidence-based manner.

Second, deepen industry coordination and collaborative development. Policy measures should be differentiated to better fit regional and sectoral needs. Coastal cities can further leverage openness and international connectivity to build green-technology exchange platforms that connect governments, financial institutions, firms, and international partners, while dedicated spillover funds can support the diffusion of core green technologies from coastal areas to inland regions. For heavily polluting industries, targeted R&D subsidy programs should prioritize the development and adoption of clean-production technologies; for other sectors, policies should emphasize improving the quality and efficiency of green innovation and increasing the conversion of innovative outputs into commercial applications. In addition, cross-regional and cross-industry collaborative innovation alliances should be encouraged to facilitate resource sharing, technical cooperation, and joint R&D, thereby enabling the replication and scaling of effective innovation practices.

Third, strengthen firms'endogenous incentives for green innovation. Policy support should combine an enabling external environment with internal governance improvements to address key barriers to green innovation. Information transparency should be strengthened to improve access to green finance, for example by enhancing the quality and comparability of ESG disclosure and linking ESG performance to the allocation and pricing of green credit (including credit limits and interest rates), so that better-performing firms can obtain financing on more favorable terms and invest more in green innovation. Meanwhile, risk-sharing arrangements and green financial services should be improved by encouraging lifecycle-based financing solutions, streamlining approval procedures for qualified green projects, and introducing professional third-party valuation services for green technologies and carbon-related assets to alleviate collateral constraints. Finally, firms should be encouraged to integrate green innovation into strategic planning, establish internal incentive mechanisms, and participate in the development of industry green standards, thereby translating policy support into sustainable innovation capability. In conclusion, by strengthening top-level design, deepening industry coordination, and reinforcing firms' endogenous incentives, policymakers can better leverage IFCPP to achieve coordinated improvements in both the quantity and quality of green innovation. At the same time, these measures can help mitigate risks such as policy arbitrage, resource misallocation, and greenwashing, thereby supporting industrial green transformation and high-quality regional economic development and generating shared benefits for the environment, firms, and local economies.

## 8.3 Research limitations

Although this paper systematically examines the impact of IFCPP on corporate green innovation and its mechanism of action, there are still several limitations that need to be objectively viewed. First, the analysis of moderating effects needs to be deepened. It has not fully explored the moderating role of contextual factors such as marketization level, digital transformation level, and industry competition intensity on the policy transmission path, making it difficult to fully present the boundary conditions of policy effects. Second, there are certain limitations in sample selection. The research objects focus on A-share listed companies, with insufficient coverage of non-listed companies, especially small and medium-sized enterprises (SMEs). These enterprises face more severe financing constraints in green transformation, which may affect the generalizability of the conclusions. Third, there are inherent limitations in variable measurement. Green innovation quality is measured by patent citation data, which is in line with academic conventions but fails to fully capture the actual environmental and economic values generated after technological commercialization; the measurement of mediating variables such as ESG performance and financing constraints also relies on existing mature indicators, which are difficult to fully cover the complex reality of corporate green transformation. Finally, although the staggered difference-in-differences method is used to control individual and time fixed effects for policy shock identification, it is still difficult to completely exclude potential interference from unobserved factors such as regional implicit policies, industry cycle fluctuations, and changes in the macroeconomic environment, which may have a slight impact on the accuracy of causal identification.

## 8.4 Future research avenues

Based on the research foundation and limitations of this paper, future research can be further expanded in the following directions: First, expand the perspective of policy synergy analysis, deeply explore the superimposed effects of IFCPP with other environmental policies such as green finance reform and innovation pilot policies, carbon market policies, and environmental inspections, and analyze the composite impact of multi-policy synergy or conflict on the "dual improvement in quantity and quality" of green innovation, so as to provide references for policy portfolio design. Second, extend the research objects and dimensions. On the one hand, non-listed companies and SMEs can be included in the sample to test the generalizability of policy effects; on the other hand, it can be extended to the industrial chain perspective to explore the transmission and spillover effects of policies among upstream and downstream enterprises, and reveal the inherent logic of industrial collaborative green transformation. Third, deepen the research on the impact of policies on the financial system. In the future, we can focus on analyzing how IFCPP affects bank credit structure, green financial product innovation, risk pricing mechanisms, etc., to provide more specific empirical evidence for the financial system to adapt to the needs of green transformation. Fourth, pay attention to the dynamic evolution of policy effects. Through longer-term data, analyze the heterogeneous impacts of policies in different stages such as pilot, promotion, and maturity, as well as the long-term mechanism after policy withdrawal, so as to provide support for the dynamic adjustment of policies.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

## Author contributions

HJ: Writing – original draft, Formal Analysis, Data curation. HL: Formal Analysis, Writing – original draft. YZ: Methodology, Conceptualization, Writing – review and editing, Software. HD: Writing – review and editing, Software.

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## Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

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