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# Impacts of Innovation Policy on Firm Green Technology Innovation Based on Evidence from a Natural Experiment in China

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# Abstract

This study examines the impact of China's National Entrepreneurship and Innovation Demonstration Bases (DBEI) on corporate green technological innovation. Utilizing a sample of 43,000 firm-year observations from 4,982 Chinese listed companies between 2010 and 2023, we employ the establishment of DBEI as a quasi-natural experiment and adopt a two-way fixed-effects difference-in-differences (DID) design to rigorously identify the causal effect and underlying transmission mechanisms. The robustness of our findings is systematically verified through multiple complementary methods—including propensity score matching (PSM), a formal parallel trends test, and a placebo test. We further conduct heterogeneity analyses across firm ownership, geographic region, and industry type. The results demonstrate that the development of DBEI significantly promotes firms' green technological innovation, with more pronounced effects among non-state-owned enterprises, firms located in eastern and central regions, and those in the manufacturing sector. Three key mediating channels are identified: digital transformation, optimization of human capital structure, and increased R&D investment. Based on these findings, we propose concrete policy implications—advancing targeted and high-quality development of DBEI, designing differentiated policy instruments tailored to heterogeneous firms and contexts, and strengthening institutional and financial support for the identified mediating pathways. Overall, this study provides both theoretical insights and actionable evidence to inform policy optimization and support corporate green transformation.


# 1. Introduction

Against the backdrop of increasing uncertainties in economic globalization and the ongoing transformation of the domestic economy, the state has promulgated policies to promote mass entrepreneurship and innovation. To advance the implementation of these initiatives, the State Council designated the first batch of 28 National Entrepreneurship and Innovation Demonstration Bases in 2016. From 2017 to 2018, the State Council issued relevant guidelines to further deepen and upgrade entrepreneurship and innovation, clarifying the functional positioning and developmental orientation of these Demonstration Bases. By 2023, a tripartite spatial layout characterized by "region + university + enterprise" had been established. Supported by relevant policies, the pivotal role of the National Entrepreneurship and Innovation Demonstration Bases in stabilizing employment, enhancing developmental momentum, and propelling reform has received growing emphasis. Currently, these bases provide comprehensive integrated services for start-ups and micro-, small, and medium-sized enterprises, encompassing entrepreneurship incubation, financing support, talent cultivation, and other critical areas. A number of high-growth technology industries have emerged from these Bases, which play a crucial role in stimulating economic growth and expanding employment.

In an era where the objectives of carbon peaking and carbon neutrality are profoundly integrated with high-quality development, green technological innovation within firms has emerged as the central driving force for overcoming resource and environmental constraints and advancing the green transformation of industries (Liu et al. 2024; Wang et al. 2024). However, enterprises encounter multifaceted challenges in pursuing green technology innovation, including substantial requirements for research and development investment, extended payback periods, and difficulties in commercializing technological outputs. On the one hand, green technology R&D must overcome multi-stage barriers—spanning from fundamental research to industrialization—which cannot be surmounted solely through firms' internal resources (Dong & Yu 2024); on

the other hand, environmental externalities lead to a divergence between the market value and social value of green technologies, thereby dampening firms' innovation incentives (Hu et al. 2023). In this context, as a critical platform for policy and resource integration, whether the tripartite "region + university + firm" layout of Demonstration Bases for Entrepreneurship and Innovation (DBEI) can provide targeted solutions for firms' green technology innovation has become a key empirical question.

This paper establishes a significant theoretical foundation for further deepening and advancing the nationwide development of DBEI. Building upon existing literature, this study offers the following marginal contributions: First, it investigates the economic impacts of DBEI development. From the perspective of innovation policies, prior research has predominantly focused on single-type or interdisciplinary policy mixes, such as green finance, environmental regulation, low-carbon city pilots, and innovative city pilot programs (Chen et al. 2022; Luo & Wang 2024; Zhang et al. 2023), examining their effects on firm financing, carbon emission reduction, and conventional technological innovation (Chen et al. 2022). Moreover, such evaluations often concentrate on specific policy instruments (e.g., green loans, environmental taxes, and fiscal subsidies), with an emphasis on macro-level regional or industry-specific analyses (Hu et al. 2023a; Zhang et al. 2022); studies on policies related to DBEI remain relatively scarce.

Second, this study elucidates the internal mechanisms through which macro-level innovation policies influence micro-level firms' green technology innovation. From the standpoint of green technology innovation, existing research has explored driving factors such as the digital economy, digital transformation, financial support, media supervision, and firm heterogeneity characteristics, primarily from a micro-level firm or market perspective (Ge et al. 2024; Hu et al. 2023; Tang et al. 2023; Wang et al. 2024), and has focused on the role of individual policy instruments (e.g., green credit, carbon trading systems) (Hu et al. 2023b; Xu 2024); few studies have examined the impact of national-level innovation policies on firms' green technological innovation.

Third, as an emerging market economy, evaluating the actual effects of policies implemented by National Entrepreneurship and Innovation Demonstration Bases on firms' green technology innovation can provide a reference for other developing and developed countries in formulating their own innovation policies.

## 2. Literature review

Amidst the concurrent context of national implementation of the innovation-driven development strategy and the objectives of carbon peaking and carbon neutrality, the National Entrepreneurship and Innovation Demonstration Base (DBEI), as a strategic platform for advancing mass entrepreneurship and innovation, has attracted significant attention. Concurrently, green technological innovation by firms has emerged as a pivotal pathway for achieving the synergistic coexistence of high-quality economic development and ecological environmental protection. What relationship exists between the development of National Entrepreneurship and Innovation Demonstration Bases and firms' green technological innovation? This paper subsequently synthesizes the extant literature from three perspectives: first, studies on policy empowerment through National Entrepreneurship and Innovation Demonstration Bases for firms, alongside innovation policy empowerment in other countries; second, research on the transmission mechanisms of firms' green

technological innovation; and third, investigations into the impact of innovation policies on firms' green technological innovation.

The government has furnished an initial impetus and institutional safeguards for firms' green technological innovation by establishing a multi-level and cross-domain policy system. This system exhibits a characteristic pattern of diversified collaboration, epitomized by the "finance-regulation-pilot" model. As a core policy instrument for targeted and precise support, green finance policies yield multi-dimensional policy effects. Research indicates that China's Green Credit Guidelines can effectively enhance low-carbon technological innovation among firms, with the core mechanism residing in augmenting R&D investment and improving management efficiency (Chen et al. 2022). However, the policy exerts significantly heterogeneous effects on high-polluting firms: it may promote incremental green innovation while suppressing radical fundamental innovation (Zhang et al. 2022). The green finance reform and innovation pilot zone policy has further validated the structural adjustment function of incentivizing green development and curbing pollution (Zhang 2023), and demonstrates greater efficacy in driving urban-level low-carbon energy transformation through advancements in green technology and innovations in green financial products (Chen et al. 2025).

The integration of fiscal and environmental regulatory instruments steers firms toward differentiated innovation trajectories. Studies demonstrate that green subsidies tend to incentivize high-risk, high-return exploratory green innovation, whereas pollution fees are more efficacious in driving low-risk, incremental exploitative green innovation (Liu et al. 2025). A complex U-shaped relationship exists between environmental regulation and green innovation, with strategic innovation exhibiting greater sensitivity to changes in environmental regulation compared to substantive innovation (Zhang et al. 2023). The environmental protection tax manifests a "double-edged sword" effect: while augmenting the quantity of green patents, it may precipitate a decline in patent quality due to managerial myopia (Wang et al. 2024).

Cross-disciplinary pilot policies and collaborative governance represent an advanced form of policy empowerment. Innovative city pilot policies can effectively mitigate the local "carbon lock-in" effect and propel low-carbon transformation in adjacent regions through spatial spillover effects (Zhao et al. 2023). The overlapping of innovative city and low-carbon city pilot policies can engender significant synergistic effects. These effects collectively foster substantive green innovation through the internalization of positive externalities from knowledge creation and negative externalities from environmental pollution (Liu et al. 2024). However, policy combinations are not invariably complementary; they may also induce "crowding-out effects" due to resource competition, a phenomenon particularly pronounced in cities with lower administrative levels or inferior resource endowments (Zhang et al. 2023). Quantitative analysis of policy texts further corroborates that a three-dimensional synergy among command-and-control, market-incentive, and public participation policies is requisite for achieving optimal pollution reduction effects (Li et al. 2023).

Nevertheless, the translation of macro-level policies into micro-level innovation behaviors of firms hinges on a series of internal and external transmission mechanisms, encompassing multiple facets such as resource acquisition, signal perception, and strategic decision-making. In the external transmission pathway, digital technology has profoundly reconfigured the resource acquisition and information environments of firms. Leveraging its extensive coverage and low-cost attributes, digital finance substantially alleviates firms' financing constraints and augments R&D investment, thereby emerging as a pivotal external driver of green

innovation (Liu et al. 2022). Internet finance has likewise been demonstrated to foster green innovation by mitigating the financing constraints of manufacturing firms, with this effect being more salient in central and western regions as well as areas with lax environmental regulations (Yu et al. 2023). The digital transformation of firms directly facilitates green technological innovation via multiple avenues, including enhancing R&D investment, reinforcing "learning by doing" and knowledge spillovers, and constructing innovation cooperation networks (Tang et al. 2023). Notably, digitalization can also stabilize expectations for innovation investment by diminishing firms' perceptions of policy uncertainty (Geng et al. 2023a). The deployment of the industrial Internet in heavily polluting industries can further elevate the level of green innovation by bolstering the organizational capabilities of firms (Guo & Liu 2024). Regarding the internal transmission pathway, firms' resource structures and managerial cognition dictate the depth and modality of policy responses. Research on financial structure reveals a significant inverted U-shaped relationship between firms' leverage ratios and green technology innovation, characterized by an optimal interval. The impacts of liabilities with varying maturities and origins differ (Wang et al. 2024). In the digital era, data resources have emerged as a pivotal factor of production, serving an indispensable intermediary role in advancing green innovation within the digital economy, with their influence demonstrating a threshold effect (Ge et al. 2024). Firms' ESG performance has been identified as the critical nexus between carbon emission reduction and green technology innovation. The promotional effect of carbon emission reduction on innovation transitions from negative to positive only when ESG performance surpasses a specific threshold, thereby elucidating the so-called "green innovation paradox" (Li et al. 2024).

Concurrently, the academic community has undertaken systematic investigations into the relationship between innovation policies and corporate green technological innovation. Utilizing multi-dimensional datasets, including samples from Chinese A-share listed companies and regional panel data, relevant studies have employed diverse empirical methodologies—such as the difference-in-differences approach, the synthetic control difference-in-differences method, and evolutionary game models—to thoroughly examine the effects, transmission mechanisms, and heterogeneous characteristics of various innovation policies. These policies encompass administrative intervention, financial support, industrial guidance, environmental regulation, fiscal and tax incentives, and regional pilot initiatives, with the literature accumulating a substantial body of research findings.

Regarding policy types and core effects, administrative incentive policies have significantly increased the quantity of green patent applications and citations among firms, with the promotional impact of command-and-control policies (e.g., laws and regulations) exceeding that of economic incentive policies (e.g., financial subsidies) (Li & Yang 2024); within the green finance policy framework, pilot reforms and innovations in green finance, along with the issuance of green bonds, foster green innovation by alleviating financing constraints, transmitting environmental commitment signals, and enhancing information disclosure (Li et al. 2025; Zeng et al. 2023). However, green credit policies exert a constraining effect on both the quantity and quality of green innovation in restricted firms, primarily through mechanisms that limit corporate debt financing (Yin et al. 2023); green industry policies (including those associated with the Five-Year Plan and Made in China 2025) effectively promote the green transformation of heavily polluting and manufacturing firms via government subsidies, the mediating effects of bank loans, tax incentives, and the transmission of corporate social responsibilities (Xu 2022; Zhu & Tan 2022); at the regional development policy level, initiatives such as industrial transformation and upgrading demonstration zones, special economic zones, national independent

innovation demonstration zones, new energy demonstration cities, and ecological civilization pilots have significantly elevated green innovation levels in regions or firms, encompassing both strategic innovation (green utility model patents) and substantive innovation (green invention patents), while exhibiting distinct regional differentiation characteristics (Bai et al. 2023; Guo et al. 2025; Liu et al. 2022; Zhang et al. 2024; Zheng et al. 2023); in terms of environmental regulation policies, the new Environmental Protection Law, total emission reduction policies, and carbon trading systems (ETS/CTS) incentivize green innovation through mechanisms such as dual-path intensive and extensive margins, as well as stakeholder attention, though the new Environmental Protection Law demonstrates a differentiated impact characterized by "quantity increase but quality decrease," and environmental taxes exhibit a nonlinear relationship of initial promotion followed by inhibition (Fan et al. 2022; Hu et al. 2023b; Jia et al. 2024; Wang & Yang 2025; Yan et al. 2024); regarding fiscal and tax incentive policies, both government subsidies and tax incentives significantly promote green innovation, with government subsidies exhibiting a stronger effect, and optimal synergy among these measures and the carbon trading system is achieved through tax refund combinations (Hu et al. 2023b; Yin et al. 2025). Furthermore, the advancement of digital government and the digital transformation of enterprises facilitate green innovation through the reduction of tax burdens, the mitigation of information asymmetry between governments and firms, and the diminution of firms' perception of policy uncertainty (Geng et al. 2023b; Hao et al. 2024a). Climate policy uncertainty (CPU) substantially constrains both the quantity and quality of green innovation via a triple mediating mechanism: inhibiting R&D investment, exacerbating financing constraints, and attenuating government green subsidies (Niu et al. 2023; Sun et al. 2024). Regulatory pressure and imitation pressure, as constituents of institutional pressure, exert a positive driving effect on green technological innovation (Qi, Jia, & Zou 2021).

Regarding transmission mechanisms, extant research has constructed a multi-dimensional framework of action pathways: policies stimulate corporate R&D investment (Li & Yang 2024), alleviate financing constraints (Li et al. 2025; Zeng et al. 2023), leverage signal effects (Zeng et al. 2023; Zhu & Tan 2022), foster the fulfillment of ESG responsibilities (Yin et al. 2025), promote industrial structure upgrading and financial development (Guo et al. 2025), accelerate talent aggregation (Zheng et al. 2023), and optimize the business environment (Hao et al. 2024b), thereby influencing green innovation through multiple channels. Certain policies exhibit distinctions in their long-term and short-term mechanisms. For instance, special economic zone policies depend on subsidy effects in the short term, whereas they realize their impacts through agglomeration effects in the long term (Liu et al. 2022). Additionally, digitalization empowers green innovation by shaping firms' perception of policy uncertainty (Geng et al. 2023b).

In terms of heterogeneity, policy effects demonstrate significant differentiation across multiple dimensions. At the level of firm ownership, state-owned enterprises (SOEs) exhibit greater advantages in green invention patent output and benefit more from policy stability, whereas private enterprises display higher sensitivity to new energy policies and green bond policies (Li et al. 2025; Zeng et al. 2023; Zhang et al. 2024). At the firm size level, the overall policy effect is more pronounced for large firms; in contrast, carbon trading policies exert a weaker positive impact on small firms, and the inhibitory effect of climate policy uncertainty on innovation quality is more substantial (Jia et al. 2024; Sun et al. 2024). Regarding industry attributes, various types of firms—such as heavily polluting firms, energy firms, manufacturing firms, and new energy firms—respond differentially to specific policies. For instance, the incentive effects of green industry policies on heavily polluting firms and of carbon trading systems on traditional energy firms are particularly significant

(Jia et al. 2024; Xu et al. 2024a; Zhu & Tan 2022). In terms of regional distribution, policy effects are generally stronger in the eastern region compared to the central and western regions, while the overall impact of fiscal and tax incentives is notable in the central region (Guo et al. 2025; Yin et al. 2025; Zheng et al. 2023). At the level of firms' intrinsic characteristics, absorptive capacity, capital structure, profitability, political connections, and environmental information disclosure levels moderate the relationship between policies and green innovation. For example, absorptive capacity positively moderates the linkage between institutional pressure and green technological innovation (Qi et al. 2021), whereas political affiliation attenuates the green innovation incentive effect of digital government (Hao et al. 2024b).

In summary, existing research has primarily focused on single or cross-disciplinary policy combinations, such as green finance, environmental regulations, low-carbon city pilots, and innovative city pilots (Chen et al. 2022; Luo & Wang 2024; Zhang et al. 2023). It emphasizes the impact of policies on firms' financing, carbon emission reduction, and traditional technological innovation (Chen et al. 2022; Luo & Wang 2024; Zhang et al. 2023), and evaluates the effects of specific policy instruments like green loans, environmental taxes, and fiscal subsidies (Chen et al. 2022; Luo & Wang 2024; Zhang et al. 2023). Most analyses concentrate on the macro-regional or specific industry levels, with research on policies related to the DBEI remaining relatively limited. Concurrently, when examining firms' green technological innovation, extant studies highlight the driving mechanisms of factors such as the digital economy, digital transformation, financial support, media supervision, and firm heterogeneity (Chen et al. 2022; Luo & Wang 2024; Zhang et al. 2023). The majority explore influencing factors from micro-level firm perspectives or market-level analyses, while few scholars investigate the impact of the DBEI on firms' green innovation. To address these gaps, this paper treats the construction of the DBEI as a quasi-natural experiment. Drawing upon a panel dataset comprising 43,000 firm-year observations from 4,982 Chinese listed companies spanning the period 2010–2023, this study employs a two-way fixed-effects difference-in-differences (DID) model to examine the influence of the DBEI on corporate green technological innovation, elucidate its underlying mechanisms, and further explore the inherent heterogeneity of this effect.

# 3. Research hypothesis

The establishment of the Demonstration Base for Ecological Industry (DBEI) offers multidimensional support for corporate green technology innovation by constructing an innovation and entrepreneurship ecosystem and integrating policy and resource elements. Its underlying mechanism can be examined through both direct effects and indirect pathways, forming the basis for the proposed research hypotheses.

The DBEI has established a comprehensive support platform for corporate green technology innovation, centered on the tripartite “region + university + enterprise” framework. From a resource provision perspective, the base alleviates capital and technological bottlenecks faced by enterprises in green innovation through services such as entrepreneurial incubation and financial support. Green technology innovation is characterized by high investment intensity and extended R&D cycles. The policy-driven financing channels and risk compensation mechanisms within the base effectively reduce innovation costs for firms and incentivize engagement in green R&D activities.

From the perspective of an innovation ecosystem, the agglomeration of high-growth technology industries within the base engenders an "innovation spillover effect" (Bao et al. 2024). Technological exchanges, talent mobility, and collaborative research and development (R&D) among enterprises facilitate the diffusion and iteration of green technologies, thereby assisting firms in overcoming critical bottlenecks in green technology development. Concurrently, the base's explicit green development orientation and policy constraints guide enterprises to integrate environmental responsibility into their innovation decisions, promoting the transition of green technology from an "optional" to a "necessary" strategic priority.

In summary, the Digital Business Ecosystem Initiative (DBEI) provides impetus and structural support for corporate green technology innovation through resource integration and ecosystem construction. Consequently, we propose Hypothesis 1 (H1).

H1: The development of DBEI promotes corporate green technological innovation.

Firstly, the DBEI fosters green technological innovation by facilitating the digital transformation of firms. Digital transformation constitutes a crucial enabling dimension in the construction of the DBEI and serves as a key linkage connecting foundational policies with corporate green innovation. On one hand, the foundation encourages firms to adopt technologies such as the Internet of Things and big data, while optimizing green research and development (R&D) processes through policies including the establishment of digital public service platforms and the provision of digital transformation subsidies (Tang et al. 2023). For example, digital monitoring systems can track real-time energy consumption and emissions data during production processes, thereby providing precise demand orientation for green technology R&D; AI-driven R&D simulation tools can shorten the testing cycles of green technologies and reduce the risks of R&D failure. On the other hand, digital transformation enhances the application efficiency and market value of firms' green technological innovations (Geng et al. 2023b; Hao et al. 2024b; Hao et al. 2024b). Through digital tools, firms can achieve deep integration of green technologies into existing production systems, improving the quality stability and production capacity of green products. Simultaneously, digital marketing tools enable accurate matching of green consumption demand, expand the market share of green products, and form a virtuous cycle of "innovation–returns–renewed innovation," further incentivizing firms to increase investments in green technology (Sun et al. 2025). Consequently, we propose Hypothesis 2 (H2).

H2: The development of the DBEI promotes corporate green technological innovation by advancing digital transformation.

Second, the DBEI elevates the level of green technological innovation by optimizing the human capital structure within enterprises. Human capital constitutes a fundamental determinant of firms' capacity for green technological innovation. The DBEI facilitates the optimization of corporate human capital through multifaceted policy instruments. From the perspective of talent supply, the initiative leverages resources from universities and research institutions to establish an industry–university–research collaborative talent cultivation system, thereby supplying firms with professionals equipped with specialized knowledge in green technologies and innovation capabilities. Concurrently, talent incentive mechanisms implemented within the ecosystem—such as housing subsidies, research funding support, and preferential treatment in professional title evaluation—effectively attract high-level external talent specializing in green innovation to join firms.

From the standpoint of talent allocation, the competitive yet cooperative environment fostered within the ecosystem encourages firms to optimize the deployment of human capital. To secure a competitive edge in green technology R&D, firms tend to allocate core talent to green innovation departments and enhance the green innovation competence of existing employees through internal training, inter-firm exchanges, and other channels. The concentration and strategic deployment of high-caliber human capital directly improve both the efficiency and quality of green technology R&D. Moreover, it stimulates innovative thinking within technical teams and helps overcome cognitive barriers associated with green technology (Xu et al. 2024badvancement. Accordingly, we propose Hypothesis 3 (H3):

H3: The development of the DBEI promotes corporate green technological innovation by optimizing the human capital structure.

Third, the DBEI elevates the level of green technological innovation by motivating firms to augment their R&D investment. R&D investment constitutes the material foundation for corporate green technological innovation. Through policy inducements and resource allocation guidance, the DBEI encourages enterprises to increase their green R&D expenditures. In terms of financial incentives, policies provided by the base—including R&D subsidies, tax exemptions (such as additional deductions for green technology R&D expenses), and preferential loan interest rates—directly alleviate the financial burden on firms engaged in green R&D (Hao et al. 2024b); simultaneously, the investment and financing matching platform established by the base facilitates connections between firms and angel investors, green funds, and other forms of social capital, thereby diversifying funding sources for green R&D. Regarding investment orientation, the base guides enterprises to allocate more R&D resources to green sectors through initiatives such as launching green technology innovation projects and organizing green technology competitions. Furthermore, the innovation achievement transformation mechanisms within the base—including technology transaction platforms and intellectual property protection services—enhance the return on green R&D investment, mitigate the marketization risks associated with innovation outputs, and reinforce firms' incentives to increase green R&D investment. This leads to the formulation of Hypothesis 4 (H4):

H4: The advancement of DBEI facilitates corporate green technological innovation by stimulating firms to increase R&D investment.

In summary, this study posits the hypothesis that the development of DBEI exerts a significant positive impact on firms' green technological innovation, with the underlying mechanisms encompassing digital transformation, optimization of human capital structure, and augmentation of R&D investment.

## 4. Models, variables and data

# 4.1 Model Construction

To precisely estimate the causal impact of the DBEI construction on firms' green technological innovation, this study employs a two-way fixed-effects difference-in-differences (DID) model, with the following basic specification:

$$Green_{i,t} = \alpha_0 + \alpha_1 Batch_i \times Time_t + \alpha_2 Batch_i + \alpha_3 Time_t + \alpha_4 Control_{i,t} + \epsilon_{i,t}$$

1

In this model, the dependent variable $Green_{i,t}$ captures the level of green technological innovation in firms, measured by the natural logarithm of the number of applications for green technology inventions and the number of authorizations. The core explanatory variable $Batch_i$ is the interaction term between the treatment group dummy variable and the policy implementation time dummy variable, with its coefficient $\alpha_1$ reflecting the net policy effect of the establishment of the DBEI. $Batch_i$ The dummy variable indicates whether a firm is located within the scope of the entrepreneurship and innovation demonstration base, $Time_t$ while denotes the time node of policy implementation; together, these constitute the foundational framework of the difference-in-differences model. $Control_{i,t}$ represents a set of multidimensional control variables encompassing the financial and operational characteristics of firms, including the asset-liability ratio, asset scale, revenue scale, profitability, return on net assets, cash flow ratio, total asset turnover, among others. The model also incorporates fixed effects for individual firms, industries, and years, thereby effectively mitigating interference from unobservable factors.

This model offers three methodological advantages. First, the difference-in-differences design compares changes between the treatment and control groups before and after policy implementation, effectively accounting for time trends and inherent group differences. Second, the inclusion of multidimensional control variables helps alleviate omitted variable bias and enhances the accuracy of the estimation results. Third, the two-way fixed-effects model captures unobservable individual heterogeneity and time-specific effects. Collectively, this framework provides a robust methodological basis for reliably identifying the causal relationship between DBEI policy and firms' green technological innovation.

# 4.2 Variable Explanation

In the empirical analysis, this study establishes a comprehensive set of variables to rigorously evaluate the impact of DBEI development on corporate green technological innovation. The dependent variable is the level of green technological innovation, operationalized as the natural logarithm of the number of green invention patent applications and grants, denoted as Green1 and Green2, respectively. Logarithmic transformation mitigates the right-skewness inherent in the raw patent count data. The core independent variable is the policy shock term within the difference-in-differences framework, constructed as the interaction between a treatment group dummy and a policy time dummy. The treatment group consists of firms located in DBEI pilot regions, whereas the control group comprises carefully matched non-DBEI firms. Policy timing is defined using a time dummy based on the specific batch to which each firm belongs.

To account for potential confounding factors, the model incorporates a series of firm-level control variables: the debt-to-asset ratio captures financial leverage; firm size and revenue size, both in logarithmic form, reflect scale effects; operating performance is indicated by a profitability dummy; return on equity (ROE) measures profitability efficiency; the cash flow ratio represents liquidity adequacy; and total asset turnover gauges operational efficiency. All continuous variables are winsorized at the 1st and 99th percentiles to reduce the influence of extreme values. This variable framework not only focuses on identifying the causal policy effect but also controls for heterogeneous firm characteristics, thereby providing a robust methodological foundation for deriving reliable empirical findings.

Table 1
Variable Definition

| | Variables | Symbols | Definitions |
|---|---|---|---|
| Dependent variable | Green technology innovation | Green1 | Ln (Number of applications for green technology inventions + 1) |
| | | Green2 | Ln (Number of authorized green invention patents + 1) |
| Core explanatory variable | Enterprises within the scope of the innovation and entrepreneurship demonstration base are impacted | Batch* Time | Virtual variable, the enterprise takes 1 in the year after policy implementation, otherwise takes 0 (DID term) generated by Batch * Time |
| | Is it a treatment group | Batch | Virtual variable, set 1 for enterprises within the scope of the innovation and entrepreneurship demonstration base, and set 0 for the matched control group enterprises |
| | Policy implementation time | Time | Virtual variable, taking 1 as the year after the implementation of the batch policy to which the enterprise belongs and 0 as the year before implementation |
| Control variables | debt-to-asset ratio | Lev | Liabilities/total assets |
| | asset size | Asset | Ln (total assets + 1) |
| | revenue scale | Reve | Ln (revenue + 1) |
| | Is it profitable | Net | Virtual variable, profit or breakeven taken as 1, loss taken as 0 |
| | Return on equity | Roe | Net profit/net assets |
| | Cash flow ratio | Cfa | Net cash flows from operating activities/total assets |
| | Total asset turnover ratio | Ato | Operating revenue/total assets |
| | digital transformation | Score | Digital Transformation (Liu et al., 2025) |
| | Human capital structure | Ratio | Proportion of employees with a bachelor's degree or above |
| | R&D investment | Rdper | Proportion of R&D personnel |

# 4.3 Data source

The data utilized in this study are sourced from the CSMAR and RESSET databases. The sample covers the period from 2010 to 2023. Observations corresponding to Special Treatment (ST) firms, delisted firms, and those with missing key variables are excluded. The final sample comprises 4,982 listed firms, yielding 43,000 firm-year observations. Among these, 1,321 listed firms are identified as being affiliated with Demonstration Bases for Entrepreneurship and Innovation (DBEI).

The identification of listed firms associated with Demonstration Bases for Entrepreneurship and Innovation (DBEI) proceeds along two dimensions:

(1) Regional DBEI: A listed firm is classified as DBEI-related if its registered address is located within a region that hosts a regional DBEI.

(2) University-and Enterprise-Affiliated Bases: For bases attached to universities or enterprises, identification is primarily achieved by matching the ultimate controlling shareholder of the listed firm. This is supplemented by manual verification using publicly available information. Specifically, a listed firm is deemed DBEI-related if it is ultimately controlled—directly or indirectly—by a university or an enterprise that operates such an innovation and entrepreneurship base.

# 4.4 Descriptive statistics

Based on a comprehensive sample of 43,000 observations, the descriptive statistics indicate that Chinese listed firms exhibit favorable performance in both green technological innovation and financial stability. Although the mean numbers of green invention patent applications and authorizations are 0.30 and 0.16, respectively, the maximum values attain 6.87 and 6.70, suggesting that certain firms have achieved a high level of green technological innovation, thereby forming a robust demonstration effect. Regarding financial indicators, the average debt-to-asset ratio for the sample firms remains at a reasonable level of 42%. The natural logarithmic means of asset size and revenue size are 22.18 and 21.47, respectively, with medians approximating the corresponding means, reflecting a relatively balanced distribution of firm size. Notably, the proportion of profitable firms in the sample reaches 88%, and the median return on equity is 7%, exceeding the average level, which indicates that most firms maintain sound profitability and operational quality. The average cash flow ratio is 5%, and the median coincides with the mean, implying stable overall cash flow conditions. The average total asset turnover is 0.59, and its distribution suggests that the overall operational efficiency of firms is maintained at a reasonable level. These statistical characteristics not only underscore the representativeness and reliability of the sample data but also lay a solid foundation for subsequent empirical analysis. Furthermore, they demonstrate that Chinese listed firms have sustained sound business conditions while pursuing innovative development.

Table 2
Descriptive statistics

| Variable | N | Mean | SD | P50 | Min | Max |
|---|---|---|---|---|---|---|
| Green1 | 43000 | 0.30 | 0.72 | 0.00 | 0.00 | 6.87 |
| Green2 | 43000 | 0.16 | 0.51 | 0.00 | 0.00 | 6.70 |
| Lev | 43000 | 0.42 | 0.21 | 0.40 | 0.06 | 0.91 |
| Asset | 43000 | 22.18 | 1.29 | 21.98 | 19.89 | 26.09 |
| Reve | 43000 | 21.47 | 1.45 | 21.32 | 18.57 | 25.35 |
| Net | 43000 | 0.88 | 0.33 | 1.00 | 0.00 | 1.00 |
| Roe | 43000 | 0.06 | 0.13 | 0.07 | -0.60 | 0.34 |
| Cfa | 43000 | 0.05 | 0.07 | 0.05 | -0.15 | 0.24 |
| Ato | 43000 | 0.59 | 0.40 | 0.51 | 0.08 | 2.27 |
| Score | 43000 | 0.16 | 0.15 | 0.19 | 0.00 | 0.76 |
| Ratio | 43000 | 0.22 | 0.18 | 0.18 | 0.00 | 0.74 |
| Rdper | 43000 | 0.17 | 0.14 | 0.13 | 0.00 | 0.96 |

# 5. Empirical Results Analysis

# 5.1 Benchmark regression

In the benchmark regression analysis of green invention patent applications (Green1), the empirical results demonstrate notable consistency. As shown in Table 3, the coefficient of the policy interaction term *Batch×Time*, which serves as the core explanatory variable, is statistically significant at the 1% level across all model specifications. This finding indicates that the development of DBEI exerts a robust stimulatory effect on firms' green technological innovation activities. With the incremental inclusion of control variables and fixed effects, the explanatory power of the model improves substantially, as evidenced by the adjusted $R^2$ rising markedly from 0.046 in the baseline model to 0.672 in the full model. This outcome reflects the appropriateness of the selected control variables and the model specification. Specifically, in the full model incorporating firm, industry, and year fixed effects, the coefficient of the policy interaction term is 0.036, suggesting that the implementation of the innovation and entrepreneurship policy has significantly increased the number of green invention patent applications among treated firms relative to the control group. Regarding the control variables, firms' revenue scale and profitability exhibit significantly positive effects, which aligns with theoretical expectations. In contrast, asset size and cash flow ratio demonstrate certain inhibitory effects, potentially reflecting the substitution effect of large-scale firms and cash-abundant firms on green innovation investment.

Regarding the quantity of green invention patent authorizations (Green2), the baseline regression results further corroborate the sustainability of the policy effects. The coefficient of the policy interaction term

remains statistically significant at a high level, ranging from 0.045 to 0.052. Moreover, upon incorporating control variables, the model's goodness of fit progressively improves to 0.618, thereby underscoring the robustness of the empirical findings. Notably, in contrast to the model for application quantity, financial indicators demonstrate a more substantial influence in the authorization quantity model. Specifically, the debt-to-asset ratio exhibits a positive and significant correlation at the 1% level, potentially indicating that moderate leverage incentivizes firms' innovation and transformation. Conversely, return on equity (ROE) shows a significantly negative association, suggesting that short-term profit pressures may constrain innovation quality. Simultaneously, the significantly negative coefficient for total asset turnover partly elucidates the trade-off between operational efficiency and innovation quality. These findings offer valuable insights into the internal mechanisms underlying the transformation of firms' green innovation outputs.

The comprehensive baseline regression results indicate that the development of DBEI has not only significantly enhanced the vitality of green technological innovation among firms but also effectively fostered the improvement of innovation output quality. This conclusion remains robust under various model specifications and alternative variable measurement approaches. The significance and sustainability of the policy effects highlight the critical role of innovation and entrepreneurship policies in steering firms' green transformation, while the heterogeneous effects of control variables unveil the intricate relationship between firm characteristics and innovation behavior. Notably, the policy exhibits a dual promotional effect on both the quantity and quality of innovation, reflecting the comprehensive efficacy of DBEI development in optimizing the innovation ecosystem. This lays a solid empirical groundwork for further investigation into the policy's transmission mechanisms. These findings not only substantiate the positive impacts of innovation and entrepreneurship policies but also furnish crucial empirical evidence for refining innovation policy design.

Table 3
Baseline results

| | Dep.= Green1 | | | Dep.= Green2 | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Batch* Time | 0.060*** | 0.041*** | 0.036*** | 0.052*** | 0.048*** | 0.045*** |
| | (4.01) | (4.02) | (3.55) | (4.90) | (6.28) | (5.89) |
| Lev | | | 0.015 | | | 0.047*** |
| | | | (0.70) | | | (2.91) |
| Asset | | | -0.023* | | | -0.024** |
| | | | (-1.77) | | | (-2.49) |
| Reve | | | 0.080*** | | | 0.056*** |
| | | | (6.63) | | | (6.07) |
| Net | | | 0.028*** | | | 0.020*** |
| | | | (2.99) | | | (2.84) |
| Roe | | | -0.039 | | | -0.057*** |
| | | | (-1.57) | | | (-3.00) |
| Cfa | | | -0.068* | | | -0.024 |
| | | | (-1.74) | | | (-0.82) |
| Ato | | | -0.109*** | | | -0.118*** |
| | | | (-5.39) | | | (-7.66) |
| Constant term | 0.265*** | 0.292*** | -0.881*** | 0.133*** | 0.148*** | -0.469*** |
| | (65.86) | (115.09) | (-7.53) | (46.92) | (77.11) | (-5.28) |
| Individual | NO | Yes | Yes | NO | Yes | Yes |
| Industry | Yes | Yes | Yes | Yes | Yes | Yes |
| Year | Yes | Yes | Yes | Yes | Yes | Yes |
| N | 43000 | 43000 | 43000 | 43000 | 43000 | 43000 |
| Adj. $R^2$ | 0.046 | 0.671 | 0.672 | 0.036 | 0.617 | 0.618 |
| F | 134.4 | 16.13 | 25.85 | 128.8 | 39.42 | 26.00 |

Note: The value of t is in parentheses; *, * *, *** respectively indicate significant at the 10%, 5%, and 1% levels; Dep. represents the dependent variable.

# 5.2 Robustness test

# 5.2.1 PSM propensity score matching

To assess the robustness of the baseline regression results, this study further employs propensity score matching (PSM) to construct matched samples for the treatment and control groups. The parallel trend test indicates that the coefficient estimates for the pre-policy period oscillate around zero and are statistically insignificant, suggesting no significant differences in green technological innovation between the treatment and control groups prior to the implementation of the DBEI policy—thereby satisfying the parallel trends assumption of the difference-in-differences (DID) model. Conversely, the post-policy period demonstrates consistently significant positive effects, confirming the dynamic impact and sustained influence of the policy. These findings effectively exclude the existence of inherent pre-policy differences between groups, further bolster the causal inference of the baseline regression results, and verify that the promotional effect of DBEI development on firms' green technological innovation originates precisely from the policy itself, rather than from pre-existing divergent trends in green innovation.

The DID estimation results based on the matched samples reveal that the coefficient of the policy interaction term exerts a significantly positive effect on both green invention patent applications and grants, with magnitude and significance levels highly consistent with the baseline regression results. As presented in Table 4, under the full model specification controlling for firm, industry, and year fixed effects, the policy interaction term increases green invention patent applications by 0.030 (significant at the 5% level), while its coefficient for grants is 0.028 (significant at the 1% level). This result robustly demonstrates that after effectively mitigating sample selection bias, the promotional effect of DBEI development on firms' green technological innovation remains robust. The goodness-of-fit of the matched model shows further improvement relative to the baseline model, with adjusted $R^2$ values reaching 0.693 and 0.645 for the two dimensions, respectively, underscoring the high quality of the matched samples. The direction and significance levels of the control variable coefficients are largely aligned with the baseline regression: revenue scale and profitability continue to exhibit significantly positive effects, while total asset turnover remains negatively correlated with green technological innovation, further validating the stability of the inherent relationship between firm characteristics and innovation behavior. The counterfactual framework constructed through PSM effectively mitigates systematic differences between the treatment and control groups, thereby enhancing the persuasiveness of the policy evaluation results and providing more rigorous empirical evidence for the core conclusion that the innovation and entrepreneurship policy promotes firms' green technological innovation.

Table 4
PSM-DID

| | Dep.= Green1 | | | Dep.= Green2 | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Batch* Time | 0.062*** | 0.035*** | 0.030** | 0.046*** | 0.031*** | 0.028*** |
| | (3.39) | (2.79) | (2.45) | (3.46) | (3.23) | (2.92) |
| Lev | | | 0.0160 | | | 0.035 |
| | | | (0.49) | | | (1.41) |
| Asset | | | -0.035* | | | -0.035** |
| | | | (-1.83) | | | (-2.35) |
| Reve | | | 0.093*** | | | 0.073*** |
| | | | (5.07) | | | (5.16) |
| Net | | | 0.032** | | | 0.023** |
| | | | (2.23) | | | (2.11) |
| Roe | | | -0.034 | | | -0.083*** |
| | | | (-0.85) | | | (-2.70) |
| Cfa | | | -0.044 | | | 0.008 |
| | | | (-0.73) | | | (0.17) |
| Ato | | | -0.127*** | | | -0.150*** |
| | | | (-4.10) | | | (-6.28) |
| Constant term | 0.285*** | 0.332*** | -0.832*** | 0.141*** | 0.172*** | -0.559*** |
| | (39.07) | (70.91) | (-4.74) | (26.81) | (47.66) | (-4.14) |
| Individual | NO | Yes | Yes | NO | Yes | Yes |
| Industry | Yes | Yes | Yes | Yes | Yes | Yes |
| Year | Yes | Yes | Yes | Yes | Yes | Yes |
| N | 23000 | 22000 | 22000 | 23000 | 22000 | 22000 |
| Adj. $R^2$ | 0.047 | 0.692 | 0.693 | 0.040 | 0.643 | 0.645 |
| F | 62.76 | 7.776 | 12.61 | 63.15 | 10.44 | 13.74 |

Note: The value of t is in parentheses; *, * *, *** respectively indicate significant at the 10%, 5%, and 1% levels; Dep. represents the dependent variable.

## 5.2.2 Placebo test

The results of the placebo test are presented in Fig. 1. The coefficient distribution derived from randomly assigning the policy treatment group and performing 500 simulation estimates approximates a normal distribution centered at zero, with the peak density occurring near zero; in contrast, the actual estimated coefficient value lies distinctly in the right tail of this random distribution. Concurrently, the p-value distribution from the random simulations is uniformly distributed over the interval from 0 to 1, further confirming that the significant policy effects identified in the baseline regression are not driven by unobserved random factors. This test result bolsters the reliability of the study's conclusions from a counterfactual perspective, demonstrating that the promoting effect of DBEI development on firms' green technological innovation is highly statistically significant and not attributable to random chance.

# 5.3 Heterogeneity analysis

## 5.3.1 By nature of firm

Heterogeneity analysis based on firm ownership nature reveals significant differences in how DBEI development promotes green technological innovation across ownership types. In terms of coefficient magnitude and statistical significance of the policy interaction term, non-state-owned enterprises (non-SOEs) demonstrate substantially stronger policy responsiveness in green technological innovation. Specifically, the coefficient in the full model reaches 0.131 and is significant at the 1% level, considerably higher than the coefficient of 0.057 for state-owned enterprises (SOEs), (which is also significant at the 1% level. This result suggests that non-SOEs, characterized by a higher degree of market orientation and more flexible operational decision-making mechanisms, exhibit greater sensitivity to innovation policy incentives and are able to translate policy benefits into tangible green technological innovation outputs more rapidly and efficiently.

Further analysis of the control variables reveals systematic differences in the drivers of green technological innovation between firms of different ownership types, reflecting distinct institutional logics underlying their innovation behaviors. For SOEs, green technological innovation activities are more closely associated with traditional financial performance indicators such as profitability. Moreover, the debt-to-asset ratio exerts a significantly positive influence on their innovation, which can be attributed to SOEs’ easier access to formal credit resources and their ability to utilize moderate debt financing—supported by implicit government credit guarantees—to fund green R&D investments. In contrast, green technological innovation in non-SOEs is more strongly driven by revenue scale expansion and asset operational efficiency. The absolute value of the total asset turnover coefficient for non-SOEs reaches 0.424, far exceeding the 0.119 observed for SOEs. Notably, the coefficient for the profitability dummy variable (Net) is -0.026 for non-SOEs and statistically insignificant, indicating that short-term profitability does not exert a discernible impact on their green innovation efforts. This phenomenon stems from the core market-driven operational logic of non-SOEs: under the incentives provided by DBEI policies, non-SOEs tend to prioritize long-term green technology innovation layout and R&D investment even amid short-term profit fluctuations, rather than adjusting their green innovation strategies based on immediate profitability. Additionally, policy supports such as R&D subsidies and tax incentives offered within demonstration bases effectively alleviate short-term financial pressures for non-SOEs’ green innovation, thereby reducing their reliance on current profit status when making innovation decisions.

Furthermore, the study reveals that profitability, as measured by Return on Equity (ROE), exerts a significantly positive effect on green technological innovation in non-state-owned enterprises (non-SOEs), whereas a negative correlation is observed for state-owned enterprises (SOEs). This indicates pronounced differences in the trade-off between innovation investment and short-term profitability across distinct ownership structures. Specifically, non-SOEs are able to establish a virtuous cycle wherein profit growth drives investment in green technological innovation, which in turn enhances market competitiveness and further improves profitability. In contrast, SOEs may encounter a conflict between short-term performance metrics and the long-term, capital-intensive nature of green innovation, resulting in the observed negative association between ROE and green technological innovation. These disparities fundamentally stem from inherent differences in resource allocation mechanisms, innovation decision-making models, and performance evaluation systems between SOEs and non-SOEs. While SOEs tend to adopt more stable innovation strategies due to institutional constraints and social responsibilities, non-SOEs develop a more market-driven and flexible innovation approach motivated by competitive pressures and profit maximization. These findings offer critical insights into the transmission mechanisms of innovation policies across firms with varying ownership types and provide a robust empirical foundation for designing targeted and differentiated policy frameworks in the further development of DBEI.

Table 5
Regression Results of Heterogeneity of Enterprise Nature

| Dep.= Green1 | SOEs | | | Non-SOEs | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Batch* Time | 0.056** | 0.063*** | 0.057*** | 0.070*** | 0.147*** | 0.131*** |
| | (2.029) | (3.775) | (3.411) | (4.063) | (9.129) | (8.236) |
| Lev | | | 0.084** | | | 0.040* |
| | | | (2.035) | | | (1.739) |
| Asset | | | -0.073*** | | | -0.105*** |
| | | | (-3.323) | | | (-6.980) |
| Reve | | | 0.099*** | | | 0.236*** |
| | | | (4.867) | | | (15.806) |
| Net | | | 0.044*** | | | -0.026 |
| | | | (2.666) | | | (-1.620) |
| Roe | | | -0.102** | | | 0.195*** |
| | | | (-2.219) | | | (4.662) |
| Cfa | | | -0.025 | | | -0.308*** |
| | | | (-0.363) | | | (-5.223) |
| Ato | | | -0.119*** | | | -0.424*** |
| | | | (-3.625) | | | (-17.058) |
| Constant term | 0.326*** | 0.355*** | -0.169 | 0.237*** | 0.232*** | -2.058*** |
| | (40.345) | (79.507) | (-0.757) | (54.202) | (52.337) | (-23.729) |
| Individual | No | Yes | Yes | No | Yes | Yes |
| Industry | Yes | Yes | Yes | Yes | Yes | Yes |
| Year | Yes | Yes | Yes | Yes | Yes | Yes |
| N | 15000 | 15000 | 15000 | 27000 | 27000 | 27000 |
| Adj. $R^2$ | 0.078 | 0.726 | 0.727 | 0.047 | 0.009 | 0.066 |
| F | 35.62 | 14.25 | 7.584 | 63.45 | 127.5 | 194.9 |

Note: The value of t is in parentheses; *, * *, *** respectively indicate significant at the 10%, 5%, and 1% levels; Dep. represents the dependent variable.

## 5.3.2 By region

The heterogeneity analysis based on regional grouping demonstrates a significant regional imbalance in the impact of the DBEI policy on green technological innovation. The policy incentive effect is most pronounced in the central region, where the coefficient of the policy interaction term registers 0.179 and is statistically significant at the 1% level. The eastern region ranks second, with a coefficient of 0.125 for the policy interaction term, also significant at the 1% level. In the western region, the policy effect is comparatively moderate yet remains statistically significant, exhibiting a coefficient of 0.043 at the 10% significance level. By contrast, the policy effect in Northeast China is statistically insignificant, indicating that firms in this region exhibit a relatively limited response to the DBEI policy in terms of green technological innovation. This regional distribution of policy effects aligns closely with disparities in China's regional economic development levels, innovation resource endowments, and policy implementation efficiency.

The stronger policy response observed in the central region stems from the dual superposition of industrial transfer dividends and targeted support from innovation and entrepreneurship policies. On the one hand, the orderly transfer of high-value-added and low-pollution manufacturing segments from the eastern to the central region has driven the upgrading of technical equipment and elevated the demand for green technological innovation among central firms, thereby laying a solid industrial foundation for the implementation of innovation and entrepreneurship policies. On the other hand, the rollout of the DBEI in the central region has been accompanied by targeted preferential measures, such as special subsidies for green technological innovation and the establishment of industry-university-research collaboration platforms, which directly address the capital and technological bottlenecks faced by local firms in pursuing green innovation. The eastern region, characterized by a mature innovation ecosystem and a dynamic market environment, has achieved efficient conversion of policy incentives into innovation outputs, resulting in a similarly prominent policy-driven effect on green technological innovation.

Further analysis of regional disparities in the control variables reveals that the revenue scale of enterprises in the eastern region exerts a particularly pronounced promotional effect on green technology innovation, with a coefficient as high as 0.349—significantly exceeding those observed in other regions. This suggests that the scale effect of firms in the eastern region can more effectively sustain research and development investment in green technologies. In the central region, the asset-liability ratio demonstrates a significantly positive impact on green technology innovation, indicating that moderate leveraged financing and the alleviation of financing constraints can effectively motivate local enterprises to engage in green innovation activities. Meanwhile, in the western region, the operating cash flow ratio shows a significant positive correlation with green technology innovation, reflecting that innovation activities in this region rely more heavily on internal cash flow support, whereas the role of external financing channels remains comparatively limited. These regionally differentiated characteristics provide important insights for formulating targeted and regionally adapted innovation policies in China, thereby deepening our understanding of the regional transmission mechanisms of such policies.

Table 6
Region Heterogeneity Regression Results

| Dep.= Green1 | East | | Central | | West | | Northeast | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| Batch* Time | 0.138*** | 0.125*** | 0.177*** | 0.179*** | 0.045* | 0.043* | -0.008 | -0.009 |
| | (8.112) | (7.520) | (5.796) | (5.884) | (1.841) | (1.740) | (-0.213) | (-0.231) |
| Lev | | -0.021 | | 0.215*** | | 0.0400 | | -0.058 |
| | | (-0.791) | | (3.774) | | (0.821) | | (-0.731) |
| Asset | | -0.191*** | | -0.0100 | | -0.0330 | | 0.0320 |
| | | (-12.423) | | (-0.273) | | (-1.128) | | (0.718) |
| Reve | | 0.349*** | | 0.061* | | 0.071*** | | 0.008 |
| | | (22.935) | | (1.795) | | (2.603) | | (0.196) |
| Net | | -0.003 | | 0.062*** | | -0.017 | | -0.003 |
| | | (-0.167) | | (2.587) | | (-0.771) | | (-0.098) |
| Roe | | 0.019 | | -0.070 | | 0.028 | | 0.037 |
| | | (0.381) | | (-1.113) | | (0.500) | | (0.452) |
| Cfa | | 0.111* | | -0.249** | | 0.265*** | | 0.048 |
| | | (1.680) | | (-2.364) | | (2.610) | | (0.322) |
| Ato | | -0.567*** | | -0.086 | | -0.108** | | -0.109 |
| | | (-22.689) | | (-1.592) | | (-2.166) | | (-1.559) |
| Constant term | 0.271*** | -2.505*** | 0.295*** | -0.884*** | 0.226*** | -0.508* | 0.168*** | -0.626 |
| | (52.656) | (-29.569) | (46.905) | (-2.822) | (36.084) | (-1.788) | (17.925) | (-1.505) |
| Individual | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Year | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| N | 29000 | 29000 | 6048 | 6048 | 5588 | 5588 | 1692 | 1692 |
| Adj. $R^2$ | 0.012 | 0.097 | 0.657 | 0.660 | 0.597 | 0.598 | 0.589 | 0.590 |
| F | 172.4 | 316.5 | 33.59 | 10.98 | 3.388 | 4.107 | 0.045 | 1.343 |

Note: The value of t is in parentheses; *, * *, *** respectively indicate significant at the 10%, 5%, and 1% levels; Dep. represents the dependent variable.

## 5.3.3 By industry

Heterogeneity analysis based on industrial attributes reveals significant inter-industry disparities in the promotional effect of the DBEI policy on green technological innovation. The manufacturing sector demonstrates a more pronounced policy response, with the coefficient of the policy interaction term in its full model reaching 0.097—significant at the 1% level—which is substantially higher than the coefficient of 0.069 observed for the non-manufacturing sector. This divergence can be attributed to the manufacturing industry's stronger technological accumulation and more robust research and development foundation, which facilitate a more effective translation of policy support into tangible innovation outputs.

Further mechanism analysis indicates that green technological innovation in manufacturing enterprises is driven by multiple factors, including the debt-to-asset ratio, asset size, and revenue scale. Among these, the debt-to-asset ratio exerts a particularly salient positive influence, with a coefficient of 0.110 significant at the 1% level, suggesting that appropriate financial leverage plays a critical role in supporting innovation activities within the manufacturing sector. In contrast, innovation activities in non-manufacturing firms exhibit distinct characteristics: the impact of asset size is statistically insignificant, while the promotional effect of revenue scale remains relatively modest.

Notably, total asset turnover exerts a significant inhibitory effect on green technological innovation across both sectors; however, this negative effect is markedly stronger within the manufacturing industry, with an absolute coefficient value of 0.265. This may reflect an inherent tension between innovation endeavors and short-term operational efficiency in the manufacturing context. Additionally, notable differences emerge regarding the impact of cash flow conditions: a significant negative correlation is observed in the manufacturing sector, whereas the effect remains statistically insignificant in the non-manufacturing sector. This suggests that innovation activities across industries exhibit fundamentally distinct patterns of financial dependency.

These findings offer important insights for understanding the industrial transmission mechanisms of innovation policies, underscoring that policy design must account for disparities in industrial characteristics and innovation models to enable targeted implementation and optimized policy efficacy.

Table 7
Industry Heterogeneity Regression Results

| Dep.= Green1 | Manufacturing | | | Non-Manufacturing | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Batch* Time | 0.064*** | 0.129*** | 0.097*** | 0.047** | 0.075*** | 0.069*** |
| | (3.230) | (7.138) | (5.616) | (2.114) | (4.902) | (4.492) |
| Lev | | | 0.110*** | | | -0.002 |
| | | | (4.288) | | | (-0.047) |
| Asset | | | 0.043** | | | -0.0200 |
| | | | (2.235) | | | (-1.150) |
| Reve | | | 0.168*** | | | 0.071*** |
| | | | (8.913) | | | (4.498) |
| Net | | | 0.024 | | | 0.010 |
| | | | (1.437) | | | (0.640) |
| Roe | | | 0.109** | | | -0.011 |
| | | | (2.368) | | | (-0.269) |
| Cfa | | | -0.278*** | | | -0.068 |
| | | | (-4.115) | | | (-1.166) |
| Ato | | | -0.265*** | | | -0.073*** |
| | | | (-9.111) | | | (-2.589) |
| Constant term | 0.286*** | 0.286*** | -4.018*** | 0.224*** | 0.247*** | -0.803*** |
| | (57.737) | (57.638) | (-45.617) | (32.642) | (56.482) | (-4.140) |
| Individual | Yes | Yes | Yes | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes | Yes | Yes | Yes |
| Year | NO | Yes | Yes | NO | Yes | Yes |
| N | 29000 | 29000 | 29000 | 14000 | 14000 | 14000 |
| Adj. $R^2$ | 0.012 | 0.007 | 0.129 | 0.117 | 0.693 | 0.694 |
| F | 89.00 | 108.1 | 422.8 | 46.04 | 24.03 | 10.35 |

Note: The value of t is in parentheses; *, * *, ***respectively indicate significant at the 10%, 5%, and 1% levels; Dep. represents the dependent variable.

# 5.4 Mechanism analysis

# 5.4.1 Digital transformation

Digital transformation serves as a critical nexus linking policy intervention to firms' green technological innovation. Drawing on Liu et al. (2025), this study examines, at the mechanism level, the mediating role of digital transformation in the relationship between innovation and entrepreneurship policy and firms' green technological innovation.

Empirical results indicate that the development of DBEI significantly accelerates firms' digital transformation, with the coefficient for the policy interaction term *Batch×Time* on the digital transformation index being 0.033, significant at the 1% level. In Column (2), the coefficient for the direct effect of digital transformation on green technological innovation is 0.190, which remains highly significant, demonstrating that digital transformation substantially enhances firms' green technological innovation. Overall, policy implementation indirectly fosters green technological innovation by promoting firms' digitalization, with digital transformation exhibiting a partial mediating effect on the policy impact. This mediating effect persists robustly after incorporating control variables.

Regarding the control variables, both asset size and revenue scale exert significantly positive effects on digital transformation, whereas return on equity and total asset turnover show inhibitory effects. This suggests that firms' digital transformation is constrained by dual factors: resource allocation efficiency and short-term profit pressures. This transmission mechanism reveals that the innovation and entrepreneurship policy not only directly incentivizes innovative behavior but, more importantly, furnishes a technical foundation and capability support for green technological innovation by driving firms' digital transformation and upgrading. Through optimizing innovation processes, enhancing R&D efficiency, and expanding technological boundaries, digital transformation significantly augments firms' potential for green technological innovation, thereby amplifying and extending policy effects.

This finding offers a novel perspective for understanding the micro-mechanisms of innovation policies and underscores the strategic significance of advancing firms' digital transformation within the context of innovation and entrepreneurship development.

Table 8
Regression Results of the Mediating Effect of Digital Transformation

| | Dep.=Score | Dep.= Green1 | Dep.=Score | Dep.= Green1 |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Batch* Time | 0.033*** | | 0.031*** | |
| | (15.93) | | (15.19) | |
| Score | | 0.190*** | | 0.151*** |
| | | (7.57) | | (5.96) |
| Lev | | | 0.034*** | 0.010 |
| | | | (7.94) | (0.46) |
| Asset | | | 0.017*** | -0.025** |
| | | | (6.65) | (-1.97) |
| Reve | | | 0.008*** | 0.079*** |
| | | | (3.25) | (6.53) |
| Net | | | 0.00200 | 0.028*** |
| | | | (1.24) | (2.95) |
| Roe | | | -0.037*** | -0.034 |
| | | | (-7.21) | (-1.35) |
| Cfa | | | -0.0120 | -0.066* |
| | | | (-1.46) | (-1.70) |
| Ato | | | -0.011*** | -0.108*** |
| | | | (-2.68) | (-5.31) |
| Constant term | 0.158*** | 0.262*** | -0.403*** | -0.820*** |
| | (304.41) | (55.69) | (-17.02) | (-6.98) |
| Individual | Yes | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes | Yes |
| Year | Yes | Yes | Yes | Yes |
| N | 43000 | 43000 | 43000 | 43000 |
| Adj. $R^2$ | 0.657 | 0.671 | 0.665 | 0.673 |

Note: The value of t is in parentheses; *, * *, *** respectively indicate significant at the 10%, 5%, and 1% levels; Dep. represents the dependent variable.

| | Dep.=Score | Dep.= Green1 | Dep.=Score | Dep.= Green1 |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| F | 253.7 | 36.74 | 144.8 | 26.95 |
| Note: The value of t is in parentheses; *, * *, *** respectively indicate significant at the 10%, 5%, and 1% levels; Dep. represents the dependent variable. | | | | |

## 5.4.2 Human capital structure

In the examination of the human capital mechanism, the empirical results delineate a critical transmission pathway through which innovation and entrepreneurship policies foster green technological innovation—namely, by optimizing the human capital structure within firms. The coefficient of the policy interaction term *Batch×Time* on the human capital ratio is 0.046, significant at the 1% level, indicating that the development of the DBEI has effectively elevated the proportion of high-quality talent in enterprises. As shown in Column (2), the direct effect of human capital structure on green technological innovation yields a coefficient of 0.068, which remains statistically significant at a high level, confirming that an optimized human capital structure substantially enhances firms' green innovation performance. Overall, the implementation of the policy indirectly promotes green technological innovation through the mediation of human capital optimization, with human capital structure exhibiting a partial mediating role in the policy impact. This mediating effect persists robustly after controlling for relevant variables. These findings demonstrate that innovation and entrepreneurship policies provide intellectual support and talent assurance for corporate green technological innovation by attracting and cultivating innovative personnel.

Regarding the control variables, asset size exhibits a significantly positive effect on human capital accumulation, whereas revenue scale exerts a negative influence—a pattern that may reflect differentiated talent strategy choices across firms of varying scales. Notably, asset turnover shows a significantly positive association with human capital but a negative correlation with green technological innovation; this contrast suggests a potential trade-off between operational efficiency and innovation-oriented human resource allocation. The inhibitory effect of the cash-flow ratio on human capital reflects a tendency among firms to prioritize production and operational expenditures over talent investment when facing financing constraints. The verification of the human capital mechanism enriches the theoretical framework of the policy's operational pathway from the perspective of innovation-factor supply, indicating that DBEI facilitates corporate green transformation not only through hardware support but also via talent-agglomeration effects. This insight carries important implications for refining policies aimed at cultivating innovative talent.

Table 9
Regression Results of the Mediating Effect of Human Capital Structure

| | Dep.= Ratio | Dep.= Green1 | Dep.= Ratio | Dep.= Green1 |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Batch* Time | 0.046*** | | 0.033*** | |
| | (12.082) | | (8.469) | |
| Ratio | | 0.068*** | | 0.069*** |
| | | (3.782) | | (3.833) |
| Lev | | | -0.019*** | 0.018 |
| | | | (-3.339) | (0.870) |
| Asset | | | 0.061*** | -0.025* |
| | | | (17.680) | (-1.930) |
| Reve | | | -0.048*** | 0.082*** |
| | | | (-14.041) | (6.764) |
| Net | | | 0.020*** | 0.027*** |
| | | | (5.066) | (2.898) |
| Roe | | | -0.017 | -0.038 |
| | | | (-1.550) | (-1.519) |
| Cfa | | | -0.082*** | -0.065* |
| | | | (-5.398) | (-1.673) |
| Ato | | | 0.031*** | -0.111*** |
| | | | (5.508) | (-5.458) |
| Constant term | 0.199*** | 0.277*** | -0.193*** | -0.887*** |
| | (174.541) | (58.059) | (-10.045) | (-7.578) |
| Individual | Yes | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes | Yes |
| Year | Yes | Yes | Yes | Yes |
| N | 43000 | 43000 | 43000 | 43000 |
| Adj. $R^2$ | 0.041 | 0.671 | 0.066 | 0.672 |

Note: The value of t is in parentheses; *, * *, *** respectively indicate significant at the 10%, 5%, and 1% levels; Dep. represents the dependent variable.

| | Dep.= Ratio | Dep.= Green1 | Dep.= Ratio | Dep.= Green1 |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| F | 927.3 | 15.21 | 303.6 | 24.62 |
| Note: The value of t is in parentheses; *, * *, *** respectively indicate significant at the 10%, 5%, and 1% levels; Dep. represents the dependent variable. | | | | |

## 5.4.3 R&D investment

As a core component of technological innovation, R&D investment plays a critical role in the mechanism through which innovation and entrepreneurship policies influence firms' green technological innovation. The results of the mechanism test reveal that the coefficient for the policy interaction term *Batch*Time* on R&D investment intensity is 0.042, which is statistically significant at the 1% level, indicating that the development of the national DBEI effectively incentivizes firms' R&D investment. In Column (2), the coefficient for the direct effect of R&D investment on green technological innovation is 0.384 and remains highly significant, demonstrating that R&D investment significantly enhances firms' green technological innovation capacity. In summary, the implementation of this policy indirectly fosters green technological innovation by augmenting firms' R&D investment, with R&D investment serving as a partial mediator in the policy's impact. This mediating effect persists robustly after controlling for relevant variables. Concerning the control variables, both asset size and revenue scale exhibit a significantly positive effect on R&D investment, reflecting the supportive role of economies of scale in firms' R&D activities. Conversely, return on equity and cash flow ratio demonstrate a significantly negative correlation with R&D investment, suggesting a potential trade-off between R&D investment and short-term financial performance. Notably, the policy interaction term remains significantly positive even after accounting for R&D investment, indicating that the innovation and entrepreneurship policy promotes green technological innovation not only through incentivizing R&D investment but also via complementary mechanisms. The verification of this mechanism enriches the theoretical framework of policy effects from the perspective of innovation resource input, demonstrating that the national DBEI effectively boosts firms' willingness and capacity for R&D investment by mitigating the externalities and financing constraints associated with R&D activities, thereby providing sustained momentum for green technological innovation. The identification of the R&D investment mechanism not only deepens the understanding of the transmission channels of innovation policies but also provides precise empirical evidence for the optimization of R&D incentive policies.

Table 10
Regression Results of the Mediating Effect of R&D Investment

| | **Dep.= Rdper** | **Dep.= Green1** | **Dep.= Rdper** | **Dep.= Green1** |
|---|---|---|---|---|
| | **(1)** | **(2)** | **(3)** | **(4)** |
| Batch* Time | 0.042*** | | 0.040*** | |
| | (26.512) | | (25.985) | |
| Rdper | | 0.384*** | | 0.349*** |
| | | (11.617) | | (10.497) |
| Lev | | | 0.014*** | 0.010 |
| | | | (4.419) | (0.467) |
| Asset | | | 0.009*** | -0.026** |
| | | | (4.371) | (-2.008) |
| Reve | | | 0.006*** | 0.078*** |
| | | | (3.015) | (6.478) |
| Net | | | -0.001 | 0.028*** |
| | | | (-0.564) | (3.025) |
| Roe | | | -0.016*** | -0.0340 |
| | | | (-4.184) | (-1.347) |
| Cfa | | | -0.020*** | -0.061 |
| | | | (-3.315) | (-1.566) |
| Ato | | | 0.00400 | -0.111*** |
| | | | (1.209) | (-5.464) |
| Constant term | 0.106*** | 0.252*** | -0.213*** | -0.807*** |
| | (270.303) | (57.953) | (-11.755) | (-6.891) |
| Individual | Yes | Yes | Yes | Yes |
| Industry | Yes | Yes | Yes | Yes |
| Year | Yes | Yes | Yes | Yes |
| N | 43000 | 43000 | 43000 | 43000 |
| Adj. $R^2$ | 0.788 | 0.672 | 0.790 | 0.673 |

Note: The value of t is in parentheses; *, * *, *** respectively indicate significant at the 10%, 5%, and 1% levels; Dep. represents the dependent variable.

| | Dep.= Rdper | Dep.= Green1 | Dep.= Rdper | Dep.= Green1 |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| F | 702.9 | 75.56 | 148.4 | 35.28 |
| Note: The value of t is in parentheses; *, * *, *** respectively indicate significant at the 10%, 5%, and 1% levels; Dep. represents the dependent variable. | | | | |

# 6. Conclusion

This study substantiates that the establishment of DBEI policy exerts a significant and robust promotional effect on corporate green technological innovation, thereby addressing a research gap in evaluating the impacts of DBEI policy on green innovation outcomes. Diverging from prior literature that predominantly examines isolated policy instruments—such as green finance or environmental regulations—or conducts macro-level analyses at regional or industrial scales, our baseline regression results, derived from a difference-in-differences (DID) model, demonstrate that the DBEI policy significantly elevates both the number of green invention patent applications and grants at the firm level. This effect remains statistically significant after controlling for firm, industry, and year fixed effects. Further robustness checks—including propensity score matching (PSM), parallel trend tests, and placebo tests—effectively mitigate concerns regarding sample selection bias and random disturbances, thereby reinforcing the causal interpretation of our findings. This contribution enriches the extant literature by furnishing empirical evidence on the economic impacts of DBEI, an innovation policy instrument that has hitherto received limited scholarly attention.

The policy effects exhibit pronounced heterogeneity across firm ownership types, regions, and industries, which advances the understanding of heterogeneous policy transmission mechanisms in emerging economies. In terms of ownership, non-state-owned enterprises (non-SOEs) exhibit a more responsive innovation behavior to DBEI policy, reflecting the adaptability of their market-oriented mechanisms in translating policy incentives into innovative outputs—a finding that complements existing studies focusing predominantly on state-owned enterprises (SOEs) or private firms in isolation. Geographically, the policy exerts a substantial impact in eastern and central regions, whereas its effect is attenuated in western and northeastern regions, underscoring disparities in regional innovation capacity and policy absorptive capacity. This extends the discourse on regional heterogeneity by revealing a distinctive gradient of “central > eastern > western > northeastern”, which contrasts with the conventional “eastern > central > western” pattern observed in prior policy evaluations. With respect to industrial attributes, the policy effect is markedly stronger in the manufacturing sector compared to non-manufacturing industries, highlighting the technology-intensive nature of manufacturing and its closer alignment with the policy’s strategic orientation. These insights offer targeted implications for industry-specific policy design—an aspect often overlooked in broader innovation policy research.

The mechanism analysis delineates three distinct yet complementary mediating channels—advancing digital transformation, optimizing human capital structure, and increasing R&D investment—through which DBEI policy indirectly enhances green technological innovation. In contrast to prior studies that predominantly examine singular mediating pathways (e.g., financing constraints, signaling effects) or firm-level micro-factors (e.g., digital economy development, ESG performance), this research demonstrates that DBEI, as an

integrated “policy-resource platform”, drives green technological innovation via a systematic “platform empowerment→capability enhancement→ innovation output” mechanism. Specifically, digital transformation strengthens firms' technological infrastructure and elevates innovation efficiency; the accumulation of high-quality human capital reinforces intellectual support for green technological innovation; and R&D investment directly expands the supply of innovation resources. Together, these three channels constitute the intrinsic transmission mechanism through which the policy effect operates, thereby enriching the theoretical framework regarding how macro-level innovation policies influence micro-level green technological innovation in firms.

Furthermore, as an evaluation of a national-level innovation policy within an emerging market context, our findings offer valuable insights for other developing and developed economies in designing innovation policies adapted to their respective institutional and economic conditions. This contribution addresses a gap in the existing literature, which has largely focused on policy impacts within individual countries or regions with limited cross-national policy learning.

## Declarations

**Funding Declaration**

No funding was received for conducting this study.

**Clinical Trial Number**: Clinical trial number: not applicable.

# Compliance with Ethical Standards:

This study does not involve human participants, animal subjects, or any sensitive personal data. It is based on publicly available or archival data from firms and policy sources. Therefore, ethical committee approval is not applicable.

# Statements and Declarations

The authors have no relevant financial or non-financial interests to disclose.

**Consent to Publish declaration: not applicable**

**Ethics approval:**

**Not applicable.**

**Consent to Participate**

**declaration: not applicable**

# Author Contribution

**M.Z. wrote the main manuscript text and prepared all figures and tables. B.H. supervised the study and provided critical revision of the manuscript. All authors reviewed and approved the final version.**

# Data Availability

**The data that support the findings of this study are available from the CSMAR database (China Stock Market & Accounting Research Database). Restrictions apply to the availability of these data, which were used under license for the current study and are not publicly available. The data are, however, available from the corresponding author upon reasonable request and with the permission of CSMAR.**

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# Figures

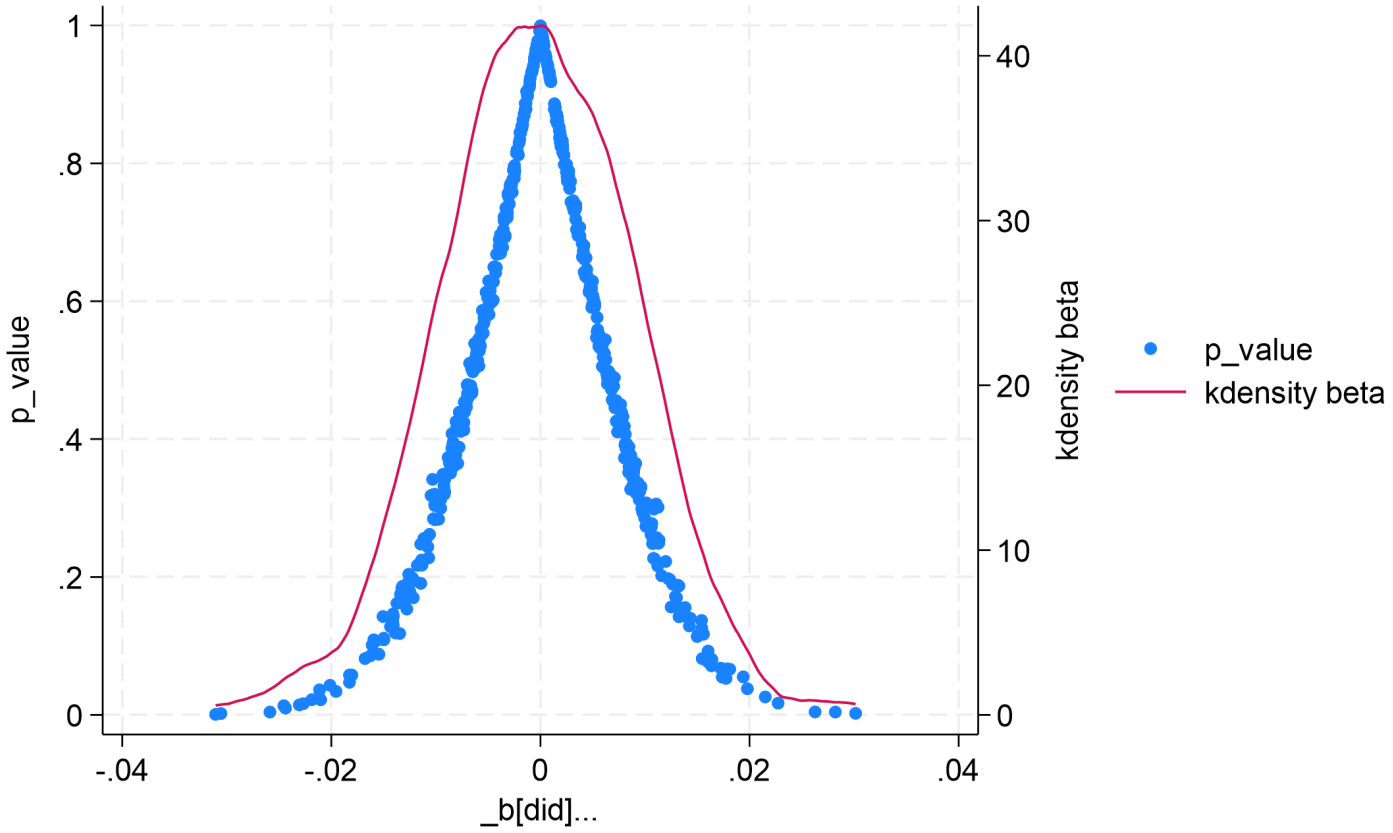



**Figure 1**

**Schematic diagram of placebo test coefficient distribution**