

The Impact of Green Finance Reform and Innovation Pilot Zone Policies on Green Technological Innovation in the New Energy Vehicle Industry

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Abstract. The green finance reform and innovation pilot zone policy aims to alleviate financial constraints on green technological innovation along the new energy vehicle (NEV) industry chain through diversified financial instruments. Based on data from listed NEV companies on the Shanghai and Shenzhen A-share markets from 2012 to 2022, this study uses a quasi-natural experiment involving three batches of pilot zones (established in 2017, 2019, and 2022) to construct a staggered difference-in-differences (DID) model to assess the policy's impact on green technological innovation. Results show that the pilot zone policy significantly promotes green technological innovation among NEV-related enterprises. The policy indirectly drives innovation by increasing R&D investment. However, financing constraints weaken the policy's effects, while firms with stronger financing capabilities benefit more. The policy impact is more pronounced for state-owned and central-western enterprises. This study provides three key insights for optimizing green finance policy: addressing financing difficulties of non-state-owned enterprises, improving the financial support system, and implementing regionally differentiated support strategies.

Keywords: green finance, reform and innovation pilot zones, green technological innovation, R&D investment, financing constraints

1. Introduction

With escalating global climate change and continued advancement of the Paris Agreement's emission targets, a green and low-carbon transition has become a common goal of the international community. As the world's largest developing country and carbon emitter, China faces the formidable challenge of achieving "carbon peaking and carbon neutrality" while maintaining stable economic growth.

To address this, since 2016 China has implemented several major reform initiatives. In August 2016, the People's Bank of China and six other ministries jointly issued the Guidelines for Establishing a Green Financial System, marking the first national-level framework for green finance policy. In June 2017, the State Council approved the establishment of the first batch of green finance reform and innovation pilot zones in five provinces—Zhejiang, Jiangxi, Guangdong, Guizhou, and Xinjiang—signaling the transition to substantive policy implementation. The pilot scope was later

expanded in 2019 and 2022 to include more central and western regions, forming a three-phase, gradual rollout.

As a technology-intensive and innovation-driven sector, the NEV industry provides an ideal case to assess the effectiveness of green finance policies. China has been the world's largest NEV market for nine consecutive years, with a market penetration rate of 31.6% in 2023, reflecting its strong momentum. However, current research has notable limitations: most studies focus on single policy tools and overlook synergies among policies; they insufficiently explore the dynamic impact of policy batches; and they rarely account for heterogeneity in firm technological characteristics. These gaps restrict policy precision and effectiveness.

To address this, we employ panel data on listed NEV firms in China from 2012 to 2022 and construct a novel staggered DID model to systematically evaluate the green finance pilot policy's impact on technological innovation. We focus on three key questions: (1) Whether and how the policy promotes green technological innovation; (2) The mediating and moderating roles of R&D investment and financing constraints; (3) Heterogeneity of policy effects across ownership types and regions. This study deepens our understanding of the policy mechanisms of green finance and offers scientific support for policy optimization, contributing to the high-quality development of China's NEV industry and its "dual carbon" goals.

2. Literature review and research hypotheses

Existing studies have confirmed that green finance policies can promote corporate innovation[1–3]. However, important research gaps remain. First, most studies focus on single policy tools[1–2], lacking a systematic analysis of synergistic effects among tools. Second, there is limited discussion on the alignment between industry-specific technological characteristics and policy design [3]. This study focuses on China's green finance reform and innovation pilot zone policy, which utilizes diversified financial instruments such as green credit and green bonds, along with fiscal support to reduce financing costs [1], and leverages institutional incentives like tax breaks to encourage R&D investment [3]. Implemented in three progressive phases (2017, 2019, and 2022), the policy forms a compound mechanism involving "financial tools – institutional incentives – market synergy" [4]. Accordingly, this paper investigates the mechanisms through which the policy affects green technological innovation in NEV firms, aiming to fill the gaps in understanding policy synergy and industry fit.

H1: The green finance reform and innovation pilot zone policy significantly promotes green technological innovation in NEV firms.

Prior studies have explored how green finance policies promote green innovation through R&D investment. Li and Zhou [5]found that dedicated funding and tax incentives substantially reduce innovation costs and directly stimulate R&D investment. Chen et al [6].showed that pilot zone policies enhance R&D efficiency by fostering industry-university-research cooperation networks, especially benefiting breakthrough innovations. Wang et al [7].argued that policy-guided social capital provides long-term funding support for R&D. Nonetheless, two critical limitations persist in current research: (1) insufficient analysis of the synergistic effects of various policy tools such as subsidies and tax incentives; (2) lack of systematic evaluation of differences in R&D conversion efficiency among firms with distinct technological traits. In response, this study emphasizes the mediating role of R&D investment. The policy reduces R&D costs through direct financial support and tax deductions, enhances R&D efficiency via innovation clusters such as industry-university platforms, and ensures long-term capital through mechanisms like green industry funds. This "cost

reduction – efficiency improvement – capital assurance” chain effectively transforms R&D input into innovation outputs, such as new technologies and improved processes.

H2: The green finance reform and innovation pilot zone policy promotes green technological innovation in NEV firms by increasing R&D investment.

Existing literature also examines how green finance policies alleviate financing constraints. Zhang and Wang [8] highlight that innovative tools such as environmental rights pledges expand financing channels. Liu et al [9] demonstrate that green certification improves credit conditions by reducing information asymmetry. Chen and Li [10] found that risk-sharing mechanisms can reduce financing costs by 15%–20%. International comparisons further suggest this effect is particularly strong in technology-intensive firms [11]. However, important gaps remain: (1) few studies systematically evaluate policy fit for firms of different sizes; (2) the threshold effect of financing constraints is underexplored. Given the characteristics of the NEV sector, this paper constructs a transmission chain of “channel expansion – cost reduction – innovation release”: the policy broadens financing access via professional financial service platforms and innovative pledge mechanisms, enhances credit status through green ratings, and ultimately eases financing constraints to unlock R&D resources. This mechanism exhibits a strong amplification effect in technology-intensive firms and offers a new perspective on the differential impacts of green finance policy.

H3: The green finance reform and innovation pilot zone policy enhances green technological innovation in NEV firms by alleviating financing constraints.

3. Variable description and model specification

3.1. Variable description

(1) Dependent Variable: Green Technological Innovation (Inva) Measured by the natural logarithm of the number of green invention patents filed by a firm in a given year plus one, i.e., $\ln(\text{green patents} + 1)$. This follows the log transformation method proposed by Hall et al [12] and the +1 adjustment by Cohen et al [13] to account for zero values.

(2) Core Explanatory Variable: Policy Implementation Effect ($\text{Treat} \times \text{Post}$) Constructed based on a staggered difference-in-differences (DID) model:

Treat (Treatment Group Dummy): Equals 1 if the firm is registered in a province covered by any of the three batches of green finance reform and innovation pilot zones, and 0 otherwise.

Post (Policy Timing Dummy): Equals 1 from the year of policy implementation onward: 2017 for the first batch, 2019 for the second, and 2022 for the third batch.

Interaction Term ($\text{Treat} \times \text{Post}$): Captures the average treatment effect of the pilot zone policy on firms in the treatment group.

(3) Control Variables: Include firm-level financial and governance characteristics: Leverage (Lev): total liabilities / total assets; Profitability (Roa): net profit / total assets; Firm Size (LnSize): natural logarithm of total assets; Ownership Concentration (Top1): shareholding ratio of the largest shareholder (%); Firm Age (LnAge): natural logarithm of firm age + 1; Executive/Shareholder Compensation (Pay): natural logarithm of executive compensation; ESG Rating (ESG): Huazheng ESG score, following You Liqun’s approach [14]

(4) Mediating Variable: R&D Investment (LnRD1) Defined as the natural logarithm of the ratio of R&D expenditure to total assets, used to measure the intensity of R&D activity while mitigating data skewness.

(5) Moderating Variable: Financing Constraints (KZ) Calculated using the Kaplan and Zingales Index (KZ Index), based on investment–cash flow sensitivity [15].

Table 1: Variable definitions and descriptions

Variable Type	Variable Name	Symbol	Definition
Dependent Variable	Green Tech Innovation	Inva	ln(number of green invention patents filed + 1)
	Treatment Group	Treat	Equals 1 if firm is in a pilot zone province, 0 otherwise
Independent Variable	Policy Implementation	Post	Equals 1 from the policy year onward, 0 before
	Policy Interaction	Treat×Post	Interaction term of Treat and Post
	Leverage Ratio	Lev	Total liabilities / total assets
	Profitability	Roa	Net profit / total assets
	Firm Size	LnSize	Natural logarithm of total assets
Control Variables	Ownership Concentration	Top1	Shareholding ratio of the largest shareholder (%)
	Firm Age	LnAge	ln(Age + 1)
	Executive Pay	Pay	Natural logarithm of executive compensation
	ESG Rating	ESG	ESG rating from Huazheng Index
Mediating Variable	R&D Investment	LnRD1	ln(R&D expenditure / total assets)
Moderating Variable	Financing Constraint	KZ	$KZ = -\beta_1 * CF/A + \beta_2 * Q + \beta_3 * D/A + \beta_4 * DIV/A - \beta_5 * C/A$

3.2. Data sources and processing

Data were obtained from the CNRDS and CSMAR databases, covering A-share listed companies in the NEV industry from 2012 to 2022, yielding 4,240 valid observations. The study excludes ST/PT firms, financial industry samples, and those with missing data. Continuous variables are winsorized at the 1st and 99th percentiles to control for outliers. Financial data come from CSMAR; green patents and executive compensation data are from CNRDS.

3.3. Model specification

Given the staggered implementation of the pilot zone policy in three phases (2017, 2019, and 2022), a multi-period difference-in-differences (DID) model is used to capture dynamic effects, following the methodologies of Beck et al [16]. and Callaway & Sant’Anna [17]. The model is specified as:

$$Inva_{i,t} = \alpha_1 + \beta_1 Treat_i \times Post_t + \sum \lambda_j X_{it} + \mu_i + \gamma_t + \epsilon_{it}$$

Where: dependent variable $Inva_{i,t}$ represents the level of green technological innovation of firm i in year t . α_1 is the constant term, and β_1 is the coefficient of the core explanatory variable $Treat_i \times Post_t$, a dummy variable indicating whether new energy firm i is subject to the green finance reform and innovation pilot zone policy in year t . This interaction term is constructed by multiplying the treatment group dummy variable $Treat_i$ with the policy timing dummy variable $Post_t$. λ_j denotes the coefficients of the control variables; μ_i and γ_t represent firm fixed effects and year fixed effects, respectively; and $\epsilon_{i,t}$ is the random error term.

3.4. Descriptive statistics

Descriptive statistics (Table 2) show substantial variation in firm-level green innovation (mean = 0.3695, SD = 0.8528). The mean of the policy interaction term (Treat $\times$ Post) is 0.0116, suggesting that only a small portion of firms were affected by the policy.

Table 2: Descriptive statistics

Variable	Description	Obs.	Mean	Std. Dev.	Max	Min
Inva	Green Technological Innovation	4240	0.3695	0.8528	4.1589	0
Treat $\times$ Post	Green Finance Reform and Innovation Policy	4240	0.0116	0.1069	1	0
lev	Leverage Ratio	4240	0.4305	0.1822	0.8540	0.0701
size	Firm Size (log of total assets)	4240	22.2016	1.2158	25.8591	19.9893
roa	Return on Assets	4240	0.0345	0.0562	0.1545	-0.2238
top	Ownership Concentration	4240	0.3255	0.1415	0.6962	0.0784
age	Firm Age (log of years since establishment)	4240	2.8550	0.3362	3.4657	1.7918
pay	Executive Compensation (log)	4240	15.3936	0.7054	17.3709	13.7418
esg	ESG Rating	4240	4.1072	0.9185	6.0000	1.5000

4. Empirical results analysis

4.1. Baseline regression results

Table 3 presents the baseline regression results. Column (1) shows that without any control variables, the coefficient of the policy interaction term Treat $\times$ Post is 0.2612 and statistically significant at the 1% level, indicating that the policy significantly improves green innovation performance. When control variables are included (column 2), the coefficient increases slightly to 0.2669 (still significant at the 1% level), suggesting that firms in the treatment group increased their green patent applications by approximately 26.69% due to the policy. This supports Hypothesis 1, confirming that the pilot zone policy, through funding support and policy signaling effects, has effectively incentivized firms to engage in green technological innovation.

Table 3: Baseline regression results

	Inva	
	(1)	(2)
Treat×Post	0.2612*** (0.0911)	0.2669*** (0.0911)
Control	NO	YES
Constant	0.3665*** (0.0065)	0.1349 (0.5832)
Firm	YES	YES
Year	YES	YES
N	4240	4240
R ²	0.7964	0.7973

Note: Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

4.2. Parallel trend assumption

To test the parallel trend assumption, this paper adopts an event study approach following Jacobson et al [18]. As shown in Figure 1, coefficients β_t for the years prior to policy implementation fluctuate around zero and are statistically insignificant, indicating that treatment and control groups followed similar pre-policy trends. Post-implementation coefficients β_t show a significant upward trend, particularly in years 4 and 5 after the policy ($p < 0.05$), suggesting a 1–2 year lag in policy effect. These findings validate the model's specification and support the causal interpretation of the results.

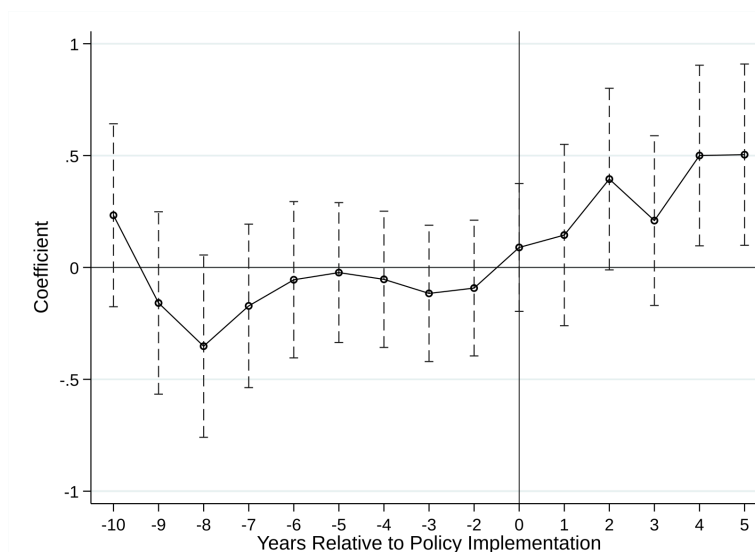


Figure 1: Parallel trend test

4.3. Robustness checks

4.3.1. Placebo test

Following the methodology of Chen et al [19]. and Yang et al [20]., a placebo test was conducted by randomly assigning firms to the treatment group 500 times. Figure 2 shows that the distribution of estimated placebo effects centers around zero (mean = -0.003, SD = 0.102), with over 90% of placebo coefficients being statistically insignificant ($p > 0.1$). The actual policy coefficient from the baseline model (0.2669, $p < 0.01$) is greater than 99.6% of the placebo estimates and clearly falls outside the simulation interval. This confirms that: (1) The baseline results are not driven by unobserved confounding factors. (2) The effect of the green finance policy on green innovation is robust and causal.

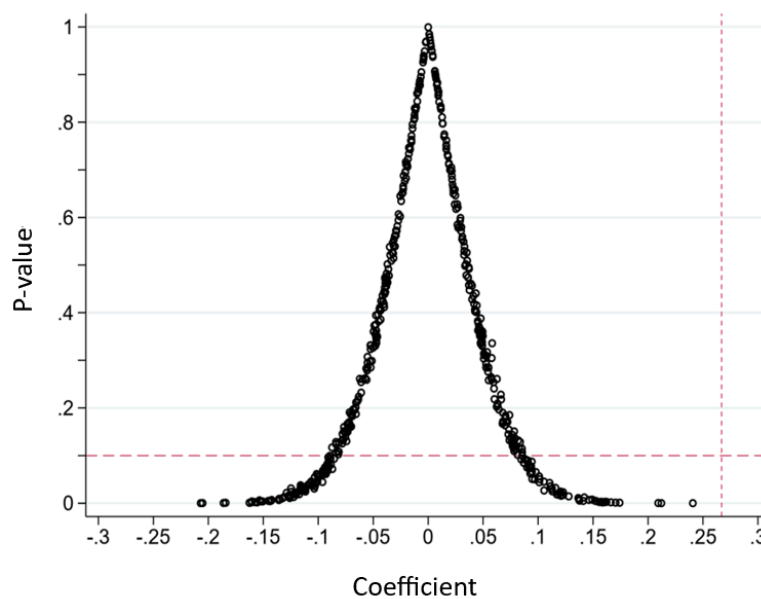


Figure 2: Placebo test

4.3.2. Propensity score matching – DID (PSM-DID)

To address potential sample selection bias, the paper employs PSM-DID using two matching strategies: kernel matching and 1:10 nearest neighbor matching, using firm financial and governance characteristics as covariates. The policy coefficients under kernel and nearest-neighbor matching are 0.2696 and 0.3127 respectively (both significant at the 1% level), closely aligned with the baseline estimate (0.2669). The balance test shows standardized differences below 10%, confirming effective matching.

Table 4: PSM-DID regression results

Variable	PSM-DID	
	Kernel Matching	1:10 Nearest Neighbor
	(1)	(2)
Treat×post	0.2696***	0.3127***
	(0.0918)	(0.1071)
Constant	0.2342	4.2308***
	(0.6690)	(1.3850)
Controls	YES	YES
Firm	YES	YES
Year	YES	YES
Industry × Year	NO	NO
N	3540	1242
R ²	0.8081	0.8621

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

5. Mechanism analysis and heterogeneity discussion

5.1. Mediation effect analysis

Using the mediation effect testing method proposed by Baron & Kenny [21], this section examines the mediating role of R&D investment (LnRD). The results are as follows: (1) The policy variable Treat × Post significantly promotes R&D investment ($\beta = 0.2359$, $p < 0.05$). After including the mediating variable, the direct effect of the policy on green patent applications drops to 0.2907 ($p < 0.01$), while the coefficient of LnRD is 0.0463 ($p < 0.01$). The Sobel test confirms the significance of the mediation effect ($z = 2.32$, $p = 0.02$), with the mediating path accounting for 15.7% of the total effect. This indicates that green finance policies enhance green innovation through a transmission mechanism of “policy incentive → R&D investment increase → green innovation.”

Table 5: Mediation effect test

Variable	LnRD	Inva
	(1)	(2)
Treat×post	0.2359**	0.2907***
	(0.0922)	(0.0956)
LnRD		0.0463***
		(0.0175)
Constant	-0.2091	0.2281
	(0.5788)	(0.6000)
Controls	YES	YES
Firm	YES	YES
Year	YES	YES
N	4112	4112
R ²	0.9313	0.7975

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

5.2. Moderation effect analysis

Table 6 tests the moderating role of financing constraints (KZ index). Results show: For firms with low financing constraints, the policy effect reaches 0.4785 ($p < 0.01$), nearly 1.8 times the baseline estimate. For firms with high financing constraints, the policy effect is insignificant (−0.2431). This suggests that financing constraints suppress the effectiveness of the policy. Firms must first alleviate funding pressures to fully benefit from green innovation incentives. Policymakers are therefore advised to supplement the policy with differentiated financial support tools to enhance overall effectiveness.

Table 6: Moderation effect test by financing constraint

Variable	High KZ (High Constraint)	Low KZ (Low Constraint)
	(1)	(2)
Treat×post	-0.2431	0.4785***
	(0.1600)	(0.1253)
Constant	0.7222	-0.7519
	(0.8699)	(1.0036)
Controls	YES	YES
Industry	YES	YES
Year	YES	YES
N	2086	2082
R ²	0.8446	0.8090

Note: *** p < 0.01, ** p < 0.05, * p < 0.1

5.3. Heterogeneity analysis

Table 7 shows that the policy has significantly heterogeneous effects: For state-owned enterprises (SOEs), the policy effect is large and significant (coefficient = 1.6933, p < 0.01). For non-state-owned enterprises, the effect is not significant (−0.1188). Regionally, central and western enterprises benefit significantly (0.4429, p < 0.01), while eastern enterprises show no significant effect (−0.2734). These findings indicate that the current policy framework favors SOEs and firms in central/western regions, while offering limited support for non-SOEs and firms in more developed areas. The results suggest a need for targeted policy differentiation and improved market-based mechanisms to ensure inclusive policy effectiveness.

Table 7: Heterogeneity by ownership and region

Variable	State-Owned	Non-State-Owned	Eastern Region	Central/Western Region
	(1)	(2)	(1)	(2)
Treat×post	1.6933***	-0.1188	-0.2734	0.4429***
	(0.2191)	(0.1036)	(0.2078)	(0.1303)
Constant	3.9762**	-1.7847***	-1.3893**	3.0294**
	(1.6204)	(0.6482)	(0.6524)	(1.3385)
Controls	YES	YES	YES	YES
Industry	YES	YES	YES	YES
Year	YES	YES	YES	YES
N	925	3315	3178	1062
R ²	0.8446	0.8090	0.8087	0.7779

6. Conclusion and policy implications

Based on panel data from A-share listed new energy vehicle (NEV) firms in China from 2012 to 2022, this study employs a multi-period difference-in-differences (DID) model to evaluate the effect of green finance reform and innovation pilot zone policies. The results indicate that the policy significantly increases the number of green invention patent applications by 26.12%, and the findings remain robust after conducting parallel trend tests, placebo tests, and PSM-DID matching. The mechanism analysis reveals that R&D investment plays a significant mediating role in the policy's effect on green innovation, while financing constraints have a negative moderating effect—firms with stronger financing capabilities are better able to translate policy incentives into innovation outcomes. The heterogeneity analysis further indicates that state-owned enterprises and enterprises in central and western regions benefit more from the policy, whereas the effects on non-state-owned and eastern region enterprises are limited.

Based on these findings, this study puts forward the following policy recommendations: (1) Optimize Green Finance Policy Tools: Develop more targeted financial instruments—such as dedicated green credit lines and green bonds—for non-state-owned enterprises, which often face financing difficulties. These tools can help lower financing costs and stimulate green innovation among these firms. (2) Improve the Financial Market Support System: Establish mechanisms such as policy-based loan guarantees and green finance risk compensation systems to alleviate financing constraints and enhance the overall effectiveness of green finance policies. (3) Implement Regionally Differentiated Support Strategies: Tailor policy implementation to regional economic, industrial, and financial characteristics. Special attention should be given to increasing financial support for central and western regions to promote more balanced regional development in green technological innovation.

The limitation of the study is that the sample only covers listed companies, which may underestimate the policy universality. Future research should be extended to non-listed firms and dynamic game models should be introduced to analyze the technology diffusion effect.

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