Financial Economics Research; Vol.3, No.1; 2026
E-ISSN: 3006-3663 P-ISSN: 3006-3655
DOI: https://doi.org/10.70267/fer.250301.103115
Published by: Zeus Press

How Does the Low-Carbon City Pilot Policy Affect Firms' Green Innovation? A Spatial DID Analysis Based on Multi-Dimensional Evidence

Xiaoyu Wu*

School of Economics, Anhui University of Finance and Economics, Bengbu, Anhui 233000, China

**Corresponding author: Xiaoyu Wu*

Abstract

Corporate green technological innovation serves as an effective pathway to promote the green transformation of economic development. This paper utilizes panel data of A-share listed companies from 2007 to 2024 as the empirical sample, taking China's "Low-Carbon City Pilot" policy as the quasi-natural experiment. Employing a multi-period difference-in-differences (DID) approach, the study empirically examines the supportive impact of this environmental protection policy on the green technological development of listed companies and explores the underlying mechanisms. The empirical results indicate that the low-carbon city pilot policy significantly enhances firms' green innovation behavior. Further mechanism analysis reveals that alleviating financing constraints and strengthening environmental governance constitute key channels through which the policy exerts its effects. On one hand, this study confirms the actual innovation-promoting effects of the low-carbon city pilot policy at the micro level; on the other hand, it elucidates the transmission pathways—optimization of the financing environment and intensification of environmental enforcement—through which the policy translates into corporate actions. These findings provide important theoretical support and practical implications for governments to refine environmental policy frameworks and enhance the endogenous incentives for firms' green development.

Keywords

low-carbon city pilot, green innovation, difference-in-differences method, financing constraints, environmental regulation

1 Introduction

The 20th National Congress of the Communist Party of China emphasized the need to follow a green development path to achieve harmony between humans and nature, and explicitly positioned the promotion of carbon peaking and carbon neutrality goals as a core component of ecological civilization construction [1]. The State Council officially released the Action Plan for Carbon Peaking Before 2030, which clearly proposes to implement low-carbon city pilot projects to explore and formulate differentiated peaking strategies. Therefore, conducting a micro-level evaluation of the innovation performance of the low-carbon city pilot policy and investigating its internal mechanisms is of great theoretical and practical significance for improving the ecological environmental governance system and promoting sustainable economic growth.

Existing research has laid an important foundation for evaluating the effects of low-carbon pilot policies. Empirical evidence shows that the policy has achieved significant results at the macro level in reducing urban carbon emission intensity [2, 3] and promoting industrial structure optimization and upgrading [4]. However, when research shifts from macro-level performance analysis to the micro-level of firm operations, current theoretical frameworks exhibit clear limitations. Regarding causal identification, although previous studies have identified a correlation between the policy and firms' green innovation behavior, the selection of pilot cities is unlikely to be random and is influenced by numerous confounding factors, making it difficult to establish a clear causal relationship between the two. Is the rapid advancement of corporate green innovation truly driven by policy effects, or is it propelled by other macro factors or intrinsic demands from firms' own development? Addressing this question requires more robust identification methods. In terms of mechanism analysis, the transmission pathways through which the policy influences firm behavior remain largely a "black box," with the operational details not fully revealed [5]. Relaxing financing constraints [6, 7] and strengthening environmental regulation [8] are considered major micro-level channels affecting the enhancement of firms' innovation activities, but these views have not yet been systematically tested. Consequently, there remains significant misunderstanding regarding the fundamental question of "how the government guides firms' innovation activities."

2 Institutional Background and Theoretical Foundation

2.1 Strategic Deployment and Implementation Pathway of the Low-Carbon City Pilot Policy

China's policy promotion and continuous progress in low-carbon city construction represent a strategic institutional innovation driven by multiple demands, including responding to the global climate crisis, fulfilling international environmental commitments, and advancing the green transformation of the economic structure. In the context of the gradual refinement of global climate governance mechanisms, China—as the world's largest carbon emitter—faces increasing international pressure and moral obligations for emission reductions [9]. To achieve the "dual carbon" strategic goals, China is transforming external pressures into endogenous development momentum and urgently needs to conduct pilot explorations in select regions to develop low-carbon development models suited to its own realities that can be shared and promoted globally. Exploring new paths for green and high-quality development has become an inevitable route to achieving sustainable socioeconomic development.

In 2010, the National Development and Reform Commission officially launched the first batch of low-carbon demonstration provinces, autonomous regions, and city pilot projects, marking the full implementation phase of the relevant policies. Over time, the second batch of pilots began in 2012 and the third batch in 2017, with the policy coverage gradually expanding and deepening. In addition, the Overall Plan for Ecological Civilization System Reform and the "dual carbon" strategy both set explicit requirements for low-carbon city pilot construction, shifting the practical connotation of the pilots from a singular focus on carbon emission intensity to a comprehensive set of objectives encompassing scientific and technological innovation, industrial optimization and upgrading, energy structure adjustment, and improvements in public quality of life. As the pilot cities are rolled out nationwide, the low-carbon city construction projects have gradually evolved into comprehensive and forward-looking policy experimental platforms, aimed at providing foundational experience and replicable practices for national carbon neutrality policies based on local implementation outcomes.

2.2 Theoretical Foundation and Research Hypotheses

2.2.1 Direct Effect: Low-Carbon Pilot Policy and Corporate Green Innovation

This paper takes the "Porter Hypothesis" as its foundational framework, emphasizing that appropriate environmental regulations can stimulate technological innovation through the "pollution offset" effect, thereby partially or fully offsetting the losses incurred from environmental expenditures and achieving a win-win situation between environmental protection and economic growth [10, 11]. The low-carbon city pilot policy increases the cost for firms to comply with environmental regulations and heightens the pressure to assume environmental responsibility, thereby strengthening external constraints on firms. This compels firms to internalize environmental costs and prompts them to engage in technological innovation and product development to reduce future governance expenses and improve production efficiency, thereby generating an "innovation compensation" effect [11]. The comprehensive low-carbon policy reform pilot projects launched at the national level send a clear signal that environmental policies will continue to strengthen, reducing firms' concerns about rising environmental costs and providing them with long-term, stable policy signals. This guides firms to prioritize green development and continuously increase investment in clean production technological innovation. Based on the above analysis, this study proposes the first empirical hypothesis:

H1: Implementation of the low-carbon city pilot policy can significantly enhance the efficiency and effectiveness of corporate green innovation.

2.2.2 Mediating Effects

2.2.2.1 The Mediating Role of Financing Constraints

Green technological innovation is characterized by long R&D cycles, imperfect patent ownership systems, and unstable expected returns, leading to limited information available to banks and other financial institutions about firms. This results in irrational allocation of financial resources and prominent difficulties in external financing for firms.

Pilot cities, by obtaining government recognition for low-carbon urban construction, signal promising low-carbon development prospects in the region to some extent. This reduces investors' screening difficulties and uncertainty regarding local firms' low-carbon projects, thereby increasing their investment willingness. Green financial instruments such as green credit guarantee funds and risk compensation mechanisms effectively alleviate risk concerns among banks and other financial institutions, enhancing their willingness to provide loans for green projects [12]. Within the green financial system promoted by the government, this mechanism connects firms with funds interested in green investment, broadening the financing channel options for real-economy enterprises. Once policy shocks reduce the degree of financing difficulties, firms will increase R&D investment intensity, closely monitor technological advancements of industry leaders, and actively mitigate the risk of innovation failure, thereby ensuring stable growth in green innovation R&D investment levels [13]. Based on the above theoretical analysis, the following mediating effect hypothesis is proposed:

H2: The low-carbon city pilot policy promotes corporate green innovation activities by alleviating financing constraints.

2.2.2.2 The Mediating Role of Environmental Regulation

Under strict environmental governance, firms face legitimacy crises in their operations. The pilot policy sets specific carbon reduction targets, which helps improve the institutional environment and regulatory constraints in cities. Influenced by the pilot policy, city governments strengthen environmental regulation, thereby increasing the pressure on firms in terms of government oversight and social scrutiny. To ensure compliance, secure government support, and reduce the likelihood of penalties, firms will pay greater attention to R&D in clean production, gradually improving their clean production levels to meet new requirements and positioning this as part of their core competitive advantage [8].

Environmental pressure compels firms to reposition their innovation investments. That is, firms must intentionally redirect funds, human resources, and technical equipment originally allocated to traditional production activities toward updating end-of-pipe treatment systems and developing clean production technologies. Although policy-induced regulatory pressure may lead to short-term increases in operating costs, in the long run it enables firms to form distinct competitive advantages in sustainable development and results in substantial increases in clean production technology outputs [11]. Accordingly, the following mediating effect hypothesis is proposed:

H3: The low-carbon city pilot policy promotes corporate green innovation through stringent environmental regulatory mechanisms.

3 Research Design and Data Sources

3.1 Model Specification

To accurately identify the mechanisms through which the low-carbon city pilot policy affects green innovation, a series of endogeneity tests are required for the model estimated in this paper. Specifically: the selection of low-carbon city pilots is not entirely random, as there may be unobservable city-level or firm-level characteristics that simultaneously influence both the pilot status and firms' innovation activities; firms' innovation behavior may reversely affect policy implementation rather than being merely passively guided by the policy; and geographical linkages across regions may generate spillover effects of the policy, and failure to adequately account for this feature could lead to biased estimation results.

To overcome the aforementioned shortcomings, this study exploits the multi-period implementation characteristics of the low-carbon city pilot projects and adopts a multi-period difference-in-differences (DID) approach to examine the policy's impact on firms' green technological innovation [14]. The following model is constructed:

$$Innovation_{it}=\beta_0+\beta_1 DID1_{it}+\rho X_{it}+\delta_i+\mu_t+\varepsilon_{it}$$

The core of the model lies in the policy variable DID_{it}, which takes the value of 1 for the year in which firm i's city enters the pilot status and thereafter, and 0 otherwise. The coefficient β_1 captures the treatment effect of the policy. To mitigate omitted variable bias, the model controls for firm-level variables X_{it} and incorporates both firm fixed effects and year fixed effects (δ_i,μ_t). ε_{it} is the random error term. This design effectively identifies the incentive effect of the low-carbon pilot policy on corporate green innovation.

3.2 Variable Selection and Data Description

This paper takes firms listed on China's A-share market from 2007 to 2024 as the initial sample. Data on listed firms' green invention patents are sourced from the China Research Data Service Platform (CNRDS), while other firm-related data come from the CSMAR database. City-level data are primarily obtained from the China City Statistical Yearbook, with linear interpolation used to fill in variables with low missing rates. Key preprocessing steps include: removing observations with missing values on critical indicators; and winsorizing numerical variables at the top and bottom 1% to mitigate the influence of outliers.

3.2.1 Dependent Variable: Corporate Green Innovation

Existing literature commonly uses indicators such as the number of green patent applications and the number of green patent grants [15]. This paper adopts the number of green patent grants by listed companies as the evaluation indicator. Compared to green patent applications, green patent grants better reflect the advanced level and practical value of firms' innovation capabilities.

3.2.2 Core Explanatory Variable: Multi-Period Difference-in-Differences Variable

This paper uses a policy dummy variable as the core independent variable for empirical testing. Based on the guidance documents issued by the National Development and Reform Commission in three batches for low-carbon pilot cities, pilot cities and their implementation timelines are identified, and the corresponding policy dummy variable is constructed: it equals 1 if city i becomes a low-carbon pilot city in period t or thereafter, and 0 otherwise.

3.3 Mediating Variables

The financing constraint indicator (SA) was first proposed by Hadlock and Pierce in 2010, with the mathematical expression: $SA=-0.737*Size + 0.043*Size^2-0.040*Age$, where Size is the natural logarithm of total assets, and Age is the firm's age since establishment [16, 17]. This index comprehensively reflects the degree of firms' external financing dependence; higher values indicate more severe financing constraints.

This paper uses the level of environmental regulation to represent the pollution status in cities. Specifically, it employs the industrial sulfur dioxide emissions and soot (dust) emissions at the prefecture-level city level, taking the natural logarithm of each variable to eliminate potential heteroskedasticity. Lower index values indicate stronger government environmental regulation intensity.

3.4 Control Variables

To control for firm heterogeneity affecting green innovation, the following firm-level control variables are included, drawing from existing literature: firm size, measured by the natural logarithm of total assets [18]; firm age; leverage ratio, measured by total liabilities divided by total assets [19]; return on assets (ROA), measured by net profit divided by total assets [19]; capital intensity, measured by net fixed assets divided by number of employees [20]; Tobin's Q, measured by market value divided by replacement cost of assets; state ownership, a dummy variable equal to 1 for state-owned enterprises and 0 otherwise [21]; shareholding proportion of the largest shareholder; proportion of independent directors, measured by the number of independent directors divided by total board members [22]; fixed asset ratio, measured by net fixed assets divided by total assets [22].

4 Empirical Analysis

4.1 Analysis of Baseline Regression Results

Table 1 presents the baseline regression results of the low-carbon city pilot policy on firms' green innovation behavior. This paper constructs a multi-period difference-in-differences model and controls for firm-specific characteristics as well as year fixed effects.

Table 1: Baseline Regression Results

	(1)
	y4
DID	0.038***
	(2.786)
Lev	-0.001
	(-0.133)
ROA	-0.000
	(-0.826)
Klratio	-0.000*
	(-1.653)
Indep	0.000
	(0.146)
Top1	0.001
	(1.231)
SOE	-0.022
	(-1.173)
Age	0.165***
	(3.661)
Size	0.199***
	(33.376)
FIXED	0.202***
	(5.010)
TQ	0.000
	(1.382)
_cons	-4.300***
	(-24.258)
N	39899
R^2	0.708

*Note: *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Numbers in parenthese s are standard errors. The same applies to the tables below.*

According to the results in column (1) of Table 2, the regression coefficient of the core variable DID is 0.038 and is statistically significant at the 1% level, indicating that the low-carbon city pilot policy has a significant positive impact on firms' green technological innovation. At the economic level, after the implementation of the low-carbon city pilot policy, firms' overall green innovation level increased by nearly 3.8%. This significant upward trend validates Hypothesis H1 proposed in this study.

4.2 Parallel Trends Test

The parallel trends assumption requires that, prior to the policy shock, the treatment and control groups exhibit consistent trends in the outcome variable, which is a prerequisite for ensuring the robustness of the difference-in-differences analysis. As shown in Table 2, the estimated coefficients in the second, third, and fourth periods before the policy implementation are insignificant and small in magnitude, indicating that there were no significant systematic differences in green innovation behavior between the treatment and control group firms prior to the low-carbon city pilot policy. This satisfies the parallel trends assumption. In the periods immediately before and the first and second periods after the policy, the coefficients are positive but do not pass significance tests. This may be attributed to the lagged nature of policy transmission and firms' responses: the process from central government policy issuance, to local governments formulating supporting rules, to firms perceiving the information, shifting resources toward R&D investment, and ultimately generating inventions requires time. Starting from the third and fourth years after policy implementation, the coefficients of the policy variable are positive and significant at the 5% level, with the coefficient values increasing over time. This indicates that the promoting effect of the low-carbon pilot policy on corporate green innovation strengthens progressively with the duration of policy implementation. The dynamic effects test confirms the validity of the parallel trends assumption and highlights the lagged and cumulative nature of the policy effects, thereby providing further validation of the baseline regression conclusions from another perspective.

Table 2: Parallel Trends Test

	(1)
	y4
pre_2	-0.003
	(-0.133)
pre_3	0.022
	(0.930)
pre_4	0.003
	(0.111)
current	0.035
	(1.526)
post_1	0.032
	(1.461)
post_2	0.029
	(1.266)
post_3	0.056**
	(2.442)
post_4	0.046**
	(2.451)
_cons	-0.544***
	(-3.983)
N	40691
R^2	0.699

4.3 Robustness Tests

4.3.1 Replacing the Dependent Variable

The baseline regression uses the number of green patents granted by firms as the dependent variable. To test robustness, this paper replaces it with the number of green patent applications to examine the relationship. Patent applications represent one of the most direct and timely indicators of firms' innovation activities, effectively reflecting the impact of policy changes on R&D expenditures and capturing early-stage investments and dynamic adjustments in firms' green innovation strategies.

The regression results are shown in column (1) of Table 3. The coefficient of the core explanatory variable DID is 0.031 and significant at the 5% level, indicating that the low-carbon city pilot policy not only increases the number of green patents granted but also significantly boosts firms' early-stage green innovation R&D investment intensity and patent output behavior. In other words, policy incentives can sustainably enhance firms' performance across various stages of green innovation.

4.3.2 Excluding Interference from Special Years

Particular attention is paid to the severe stock market volatility in China's A-share market in 2015, which affected firms' financing costs and investor expectations, thereby influencing R&D investment willingness and technological innovation activities. The sudden outbreak of the COVID-19 pandemic in 2020 also exerted a massive shock on the global economy, with potential effects that could either stimulate breakthrough innovation or hinder traditional development models.

After excluding observations from 2015 and 2020 and re-estimating the baseline regression, the results in column (2) of Table 3 show that the estimated coefficient of the core explanatory variable DID remains 0.038 and passes the 1% significance test. This indicates that, after controlling for major external shocks, the low-carbon city pilot policy continues to significantly promote firms' green technological innovation. The findings are not driven by other important factors, and these factors did not undergo significant changes during the study period, thereby enhancing the robustness of the conclusions.

Table 3: Robustness Tests

	(1)	(2)
	y3	y4
DID	0.031**	0.038***
	(1.992)	(2.669)
Lev	-0.001	-0.000
	(-0.164)	(-0.006)
ROA	-0.000	-0.000
	(-0.490)	(-0.672)
Klratio	-0.000*	-0.000*
	(-1.744)	(-1.660)
Indep	-0.000	-0.000
	(-0.262)	(-0.182)
Top1	0.000	0.001
	(0.474)	(1.603)
SOE	-0.020	-0.020
	(-0.940)	(-0.991)
Age	0.044	0.170***
	(0.851)	(3.602)
Size	0.237***	0.202***
	(34.733)	(31.692)
FIXED	0.052	0.200***
	(1.121)	(4.615)
TQ	0.001	0.000
	(1.361)	(1.105)

4.4 Mechanism Analysis

4.4.1 Mechanism of Alleviating Financing Constraints

The results in column (1) of Table 4 show that DID has a positive effect on the financing constraint index (SA) at the 1% significance level. Since the SA index is negative, a decrease in its absolute value indicates a reduction in firms' financing constraints, confirming that the financing constraint channel plays an important role in the low-carbon city pilot policy's promotion of corporate green innovation. The top-down pilot policy supported by the central government conveys positive, effective, and sustainable signals about regional green development to capital markets. Commercial banks use this as a basis to reduce valuation biases and transaction costs for green projects, optimizing their asset allocation strategies. This manifests as more lenient credit conditions, lower interest rates, and longer credit cycles for qualifying firms and green development projects in pilot areas [6]. In this context, local governments, to implement the pilot policy, often introduce supportive measures such as green credit interest subsidies, risk compensation funds, and incentives for green bond issuance[23], which significantly improve firms' financing conditions.

Financial resources flowing into firms under government guidance often carry environmental attributes or designated-use restrictions. The distinctive feature of these financing instruments is their targeted nature, directing funds toward firms' green development areas. Consequently, while firms experience scale expansion, incentive effects lead to greater concentration of innovation investment in environmentally friendly technology R&D, green manufacturing process improvements, and green product development, resulting in substantial increases in green patent outputs and achieving high-quality development [13].

4.4.2 Environmental Regulation Mechanism

As shown in columns (2) and (3) of Table 4, the coefficients of DID on industrial sulfur dioxide emissions and soot (dust) emissions are negative and significant at the 1% level. Since these indicators are inverse proxies for environmental regulation strength, the results indicate that after the implementation of the low-carbon city pilot policy, local environmental supervision and enforcement capabilities have substantially improved.

From an institutional incentive perspective, governments raise firms' violation costs and environmental requirements through stringent regulations and enhanced enforcement. To adapt to higher standards, reduce penalty risks, or even avoid shutdowns, firms must adopt technological innovation measures. This generates demand for end-of-pipe treatment improvements and clean production technology development. From a resource reallocation perspective, under environmental regulatory pressure, the relative importance of internal resources shifts. Facing increasingly strict regulations, firm managers redirect funds, labor, and technical facilities originally allocated to non-green activities toward pollution control, energy conservation, emission reduction, and green product R&D [8]. Finally, as environmental regulation strengthens over time, firms must not only achieve one-time innovations but also develop continuous learning capabilities, internal and external green development capacities, and the ability to acquire external advancements to better respond to regulatory changes [11].

Table 4: Mechanism Analysis

	(1)	(2)	(3)
	SA	SO2	Soot_Emissions
DID	0.018***	-0.190***	-0.055***
	(10.165)	(-16.707)	(-3.353)
Lev	0.016***	-0.013***	-0.027***
	(27.163)	(-3.315)	(-2.955)
ROA	0.000***	-0.000***	-0.000***
	(16.519)	(-4.304)	(-6.323)
Klratio	0.000	-0.000	-0.000
	(1.398)	(-1.220)	(-1.515)
Indep	0.000***	-0.002***	-0.001
	(3.392)	(-2.813)	(-0.549)
Top1	0.001***	-0.001	-0.001**
	(10.107)	(-1.330)	(-2.403)
SOE	-0.024***	-0.044***	0.082***
	(-9.567)	(-2.807)	(3.373)
Age	-0.125***	-0.130***	-0.095
	(-21.077)	(-3.417)	(-1.472)
Size	-0.008***	-0.006	0.016**
	(-9.618)	(-1.141)	(2.048)
FIXED	0.009*	0.029	0.037
	(1.658)	(0.871)	(0.755)
TQ	0.001***	-0.000	-0.000
	(17.000)	(-0.595)	(-0.040)
_cons	-3.323***	10.292***	9.441***
	(-142.357)	(68.867)	(38.981)
N	39899	39280	26453
R^2	0.939	0.916	0.877

4.5 Heterogeneity Analysis

Based on the baseline regression, the low-carbon city pilot policy exerts a sustained positive effect on the green innovation of sample listed firms. This section further examines whether this effect varies across firm characteristics, conducting heterogeneity analyses from the perspectives of ownership nature and firm size.

4.5.1 Heterogeneity by Ownership Nature

As shown in columns (1) and (2) of Table 5, after controlling for firm characteristics, the estimated coefficient of DID is positive and significant at the 1% level in the state-owned enterprise (SOE) subsample, but insignificant in the non-SOE subsample. This indicates that the low-carbon city pilot policy has a clear promoting effect on green innovation capabilities in SOEs but not in private enterprises. The reason may lie in differing credit constraints faced by SOEs and private firms. Implicit government guarantees associated with policy connections and expectations of soft budget constraints provide SOEs with lower-cost credit resources, enabling them to more easily convert policy benefits into reduced actual financing constraints and thereby promote green innovation activities.

4.5.2 Heterogeneity by Firm Size

As shown in columns (3) and (4) of Table 5, the DID coefficient is significantly positive in the large-firm subsample but insignificant in the small-firm subsample. This suggests that the policy's positive impact on green technological innovation primarily manifests in large firms. This is attributable to endogenous economies of scale and internal adjustment flexibility. Green technological innovation R&D involves high initial investments; large firms can allocate substantial R&D expenditures across diverse projects, reducing per-project innovation costs and generating economies of scale advantages. Moreover, with strong research capabilities, talent reserves, and extensive collaboration networks, large firms possess superior knowledge transformation and innovation capacities, enabling them to better understand and track policies and rapidly translate them into productivity.

4.5.3 Heterogeneity by Industry Pollution Attributes

As shown in columns (5) and (6) of Table 5, the policy variable DID is significantly positive in the non-heavy-polluting firm subsample but insignificant in the heavy-polluting subsample. This indicates that the policy has a greater promoting effect on green innovation in non-heavy-polluting firms. For non-heavy-polluting firms, there often remains a substantial technological gap between current production processes and industry-leading levels. Under policy incentives, green innovation can often proceed through incremental improvements within existing technological frameworks, which are more easily supported compared to radical transformations from traditional paths, and responses to policy incentives are more timely. In contrast, deep pollution control transformations in heavy-polluting industries typically involve bold changes to existing production processes and face significant path dependence and sunk cost issues. Even with policy incentives in place, firms struggle to achieve technological breakthroughs commensurate with the incentive intensity in the short term.

Table 5: Heterogeneity Analysis

	(1)	(2)	(3)	(4)	(5)	(6)
	y4	y4	y4	y4	y4	y4
DID	0.075***	-0.006	0.053**	-0.012	0.038**	0.049
	(3.186)	(-0.379)	(2.360)	(-0.759)	(2.457)	(1.375)
Lev	-0.000	-0.012**	-0.048	-0.003	0.000	0.037
	(-0.001)	(-2.055)	(-1.048)	(-0.574)	(0.086)	(0.758)
ROA	0.001*	-0.000**	0.001	-0.000	-0.000	0.001*
	(1.867)	(-1.977)	(1.320)	(-1.402)	(-1.299)	(1.729)
Klratio	-0.000*	-0.000	-0.000	0.000	-0.000	0.000
	(-1.691)	(-1.171)	(-0.529)	(0.241)	(-1.566)	(0.915)
Indep	0.000	-0.000	0.000	0.001	-0.000	0.001
	(0.122)	(-0.097)	(0.334)	(1.327)	(-0.153)	(0.270)
Top1	-0.003***	0.000	0.002***	-0.001*	-0.000	0.003**
	(-3.527)	(0.560)	(2.777)	(-1.753)	(-0.716)	(2.314)
SOE	0.000	0.000	-0.086***	0.021	-0.027	0.071
	(.)	(.)	(-2.848)	(0.883)	(-1.308)	(1.227)
Age	0.685***	0.108**	0.584***	-0.006	0.238***	-0.638***
	(8.091)	(1.974)	(7.375)	(-0.098)	(4.844)	(-4.794)
Size	0.230***	0.214***	0.275***	0.157***	0.204***	0.224***
	(17.408)	(30.005)	(21.174)	(17.584)	(30.637)	(12.764)
FIXED	0.127*	0.319***	0.051	0.049	0.315***	-0.010

	(1.707)	(6.451)	(0.713)	(1.050)	(6.507)	(-0.108)
TQ	-0.006	0.001*	-0.002	0.000	0.000	0.022***
	(-0.867)	(1.819)	(-0.227)	(0.819)	(1.222)	(3.280)
_cons	-6.404***	-4.424***	-7.229***	-2.949***	-4.605***	-2.631***
	(-16.574)	(-21.124)	(-19.225)	(-13.026)	(-23.149)	(-5.263)
N	12773	27080	21052	18415	30838	6488
R^2	0.759	0.688	0.773	0.613	0.720	0.688

5 Conclusions and Policy Recommendations

Based on the aforementioned analytical framework, this paper takes China's "Low-Carbon City Pilot" policy as the quasi-natural experiment and employs panel data of A-share listed companies from 2007 to 2024 for empirical testing. A multi-period difference-in-differences (DID) model is constructed to investigate how this policy promotes green innovation activities, the channels through which it operates, and whether these effects exhibit heterogeneity across different types of firms. The main research conclusions are as follows:

The baseline regression results demonstrate that the low-carbon city pilot policy exerts a significant promoting effect on corporate green innovation. Mechanism analysis further identifies two key transmission pathways through which the policy functions. In terms of alleviating financing constraints, the pilot policy sends a clear signal of green transformation, prompting banks and government agencies to actively respond by providing corresponding credit support and preferential tax treatments to green enterprises, effectively reducing firms' external financing pressures. Regarding environmental regulation, local governments in pilot areas intensify environmental enforcement, thereby elevating the level of environmental protection. Stricter enforcement increases the cost of violations for firms, guiding the reallocation of production factors toward ecological and environmental protection, fostering firms' endogenous motivation for green development, and stimulating them to engage in green technological innovation to address regulatory pressures and establish new competitive advantages.

Heterogeneity analysis reveals that the policy's impact varies across firm types. In terms of ownership structure, the policy has a stronger effect on state-owned enterprises' green technological innovation, while its impact on other types of enterprises is relatively limited. This may be attributed to the closer ties between state-owned enterprises and government departments, which provide them with greater convenience in accessing policy benefits, including implicit guarantees that enhance their financing capacity and facilitate green innovation activities. At the firm size level, large enterprises benefit more from policy support than small ones, as they can leverage economies of scale to reduce R&D costs, accumulate more specialized knowledge, and possess stronger management teams, enabling them to better capitalize on policy opportunities. In terms of industry pollution attributes, the policy's promoting effect is greater on non-heavy-polluting industries compared to heavy-polluting ones. For non-heavy-polluting firms, there remains a substantial technological gap between their current production processes and green technology frontiers; thus, pursuing incremental green innovation yields higher marginal returns with lower switching costs. In contrast, heavy-polluting firms face complex technological substitution challenges in achieving full green transformation, compounded by path dependence and sunk costs, making it difficult for them to rapidly realize innovation performance commensurate with policy incentives in the short term.

Drawing on the above analysis, this paper offers the following policy recommendations to provide insights for firms' green transformation strategies:

First, establish a coordinated policy system integrating regulatory mechanisms and green finance. Environmental protection and green finance policies should be synergized to mutually reinforce green development. National and local governments should, while strengthening environmental supervision and strict enforcement, coordinate the planning of multi-level, multi-dimensional, and targeted green financial systems. This would address financing difficulties in green innovation—particularly for small, medium, and micro enterprises as well as private firms—by combining external pressures from ecological protection with internal driving forces from financial service mechanisms.

Second, implement differentiated policies to enhance the effectiveness of targeted incentives. For private and small/micro enterprises, provide special funds for green technological upgrading, implement a value-added tax "levy first, refund later" system for clean production products, and other measures to improve their green technological innovation capabilities. For state-owned enterprises, strengthen their guiding role in green technological innovation and leverage their resource advantages across industries to form alliances that promote collaborative R&D activities among upstream and downstream firms.

Third, summarize pilot experiences and promote the diffusion of inter-regional synergistic effects to build a nationwide innovation collaboration network. Systematically summarize the governance models from the three batches of low-carbon pilot cities that have promoted corporate green innovation, while intensifying exchanges and cooperation among pilot areas. This would create a process of piloting first, summarizing experiences, and then replicating them to other regions, ultimately forming a nationally coordinated green technological innovation system and transformation framework

References

[1] Zhang, M. Q. Implementing the spirit of the 20th CPC National Congress to promote the building of a modern society where humanity and nature coexist harmoniously within the framework of the rule of law. Environment and Sustainable Development. 2023, 48(1), pp. 23-25. https://doi.org/10.19758/j.cnki.issn1673-288x.202301023.

[2] Song, H., Sun, Y. J. and Chen, D. K. Evaluation of the effectiveness of government air pollution control: An empirical study of China's "low-carbon city" construction. Managing the World. 2019, 35(6), pp. 95-108. https://doi.org/10.3969/j.issn.1002-5502.2019.06.009.

[3] Su, T. Y., Yu, Y. Z. and Pan, J. X. The carbon reduction effect of dual pilot projects in low-carbon cities and innovative cities: A synergistic perspective based on green innovation and industrial upgrading. Science of Science and Management of Science and Technology. 2022, 43(1), pp. 21-37.

[4] Lu, J., Wang, X. F. and Liu, L. The Industrial Structure Upgrading Effect of Low-Carbon City Policies: A Quasi-Natural Experiment Based on Low-Carbon City Pilot Projects. Journal of Xi'an Jiaotong University (Social Sciences Edition). 2020, 40(2), pp. 104-115. https://doi.org/10.15896/j.xjtuskxb.202002012.

[5] Xu, J. and Cui, J. B. Low-carbon cities and green technology innovation in enterprises. China's Industrial Economy. 2020(12), pp. 178-196. https://doi.org/10.3969/j.issn.1006-480X.2020.12.016.

[6] Wang, X. and Wang, Y. Research on Green Credit Policies to Promote Green Innovation. Managing World. 2021, 37(6), pp. 173-188. https://doi.org/10.3969/j.issn.1002-5502.2021.06.029.

[7] Zhao, Z. z., Cheng, Z. and Lü, D. s. Has the national low-carbon strategy improved the total factor productivity of enterprises?: A quasi-natural experiment based on low-carbon city pilot projects. Industrial Economics Research. 2021(6), pp. 101-115.

[8] Chen, F. Y. and Guo, X. Regional Environmental Pressures and Corporate Green Innovation: A Study Based on Low-Carbon City Pilot Policies. Accounting Communication. 2022(21), pp. 49-53,59.

[9] Lin, Y. Q. Research on global economic governance reform and the enhancement of institutional discourse power of emerging countries. Social Sciences. 2020(11), pp. 16-28.

[10] Porter, M. E. and van der Linde, C. Toward a New Conception of the Environment-Competitiveness Relationship. Journal of Economic Perspectives. 1995, 9(4), pp. 97-118. https://doi.org/10.1257/jep.9.4.97.

[11] Wang, G. y. and Wang, D. Porter's hypothesis, environmental regulation, and corporate technological innovation: A comparative analysis of the Middle East and central regions. Chinese Soft Science. 2011(1), pp. 100-112. https://doi.org/10.3969/j.issn.1002-9753.2011.01.011.

[12] Duan, R. A Study on the Impact of Green Credit on Enterprise Transformation and Upgrading. Master's Thesis, Guiyang: Guizhou University of Finance and Economics, 2019.

[13] Ye, C. H. Financing constraints, government subsidies and corporate green innovation. Statistics and Decision. 2021, 37(21), pp. 184-188. https://doi.org/10.13546/j.cnki.tjyjc.2021.21.038.

[14] Goodman-Bacon, A. Difference-in-differences with variation in treatment timing. Journal of Econometrics. 2021, 225(2), pp. 254-277. https://doi.org/https://doi.org/10.1016/j.jeconom.2021.03.014.

[15] Qi, S. Z., Lin, S. and Cui, J. B. Can the environmental rights trading market induce green innovation?: Evidence based on green patent data of listed companies in my country. Economic Research. 2018, 53(12), pp. 129-143.

[16] Hadlock, C. J. and Pierce, J. R. New evidence on measuring financial constraints: Moving beyond the KZ index. The review of financial studies. 2010, 23(5), pp. 1909-1940. https://doi.org/10.1093/rfs/hhq009.

[17] Xing, H., Xia, Z. L. and Ma, J. Can the integration of industry and finance correct inefficient corporate investments?: From the perspective of financial institutions holding shares in real economy enterprises. Financial Development Research. 2021(12), pp. 45-51. https://doi.org/10.19647/j.cnki.37-1462/f.2021.12.006.

[18] Tong, A. Q. and Chen, W. An empirical study on the impact of government subsidies on corporate R&D investment: A new perspective based on political connections of private listed companies on the sme board. Science Research. 2016, 34(7), pp. 1044-1053. https://doi.org/10.3969/j.issn.1003-2053.2016.07.010.

[19] Jiang, S. S. and Liu, G. Y. A study on the impact of venture capital and information transparency on corporate innovation willingness. Journal of Management. 2021, 18(8), pp. 1187-1194. https://doi.org/10.3969/j.issn.1672-884x.2021.08.009.

[20] Jing, W. M. and Zhu, D. S. The impact of environmental governance on corporate R&D investment. Theory and Modernization. 2021(3), pp. 35-45. https://doi.org/10.3969/j.issn.1003-1502.2021.03.005.

[21] Ni, J. and Kong, L. W. Environmental information disclosure, bank credit decisions, and debt financing costs: Empirical evidence from a-share listed companies in heavily polluting industries in shanghai and shenzhen stock exchanges. Economic Review. 2016(1), pp. 147-156,160.

[22] Liu, X. G. and Li, Z. Y. Research on the impact of financial flexibility and financing constraints on innovation investment. Business and Economics. 2021(10), pp. 70-72,164. https://doi.org/10.3969/j.issn.1009-6043.2021.10.024.

[23] Xie, X. M., Wang, R. Y. and Huo, J. G. Green technology innovation and firm performance under government financial incentives: An empirical study based on content analysis. Management Comments. 2020, 32(5), pp. 109-124.

Funding
This research received no external funding.

Conflicts of Interest
The authors declare no conflict of interest.

Acknowledgment

This paper is an output of the science project.