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Evaluating the Impact of Low-Carbon Urban Policy on Corporate Green Innovation—Evidence from China's National Low-Carbon City Strategy Program

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Abstract: Low-carbon urban policy (LCUP) and corporate green innovation are considered crucial strategies and methods for reducing urban carbon emissions, addressing climate change, and promoting urban environmental sustainability. This study constructed a quasi-natural experiment based on the low-carbon city strategy program implemented in China in 2010, utilizing data from Chinese prefecture-level cities and publicly listed companies from 2005 to 2020. Employing a multi-period difference-in-differences (DID) approach, this paper reveals that the establishment of low-carbon model cities effectively fosters green innovation in corporations. Further analysis demonstrates that this promotional effect is particularly significant in non-state-owned enterprises, enterprises with high media attention, those with a high level of digitalization, and enterprises located in cities with high levels of green finance and in the Eastern and Central regions of China. These conclusions withstood a series of robustness tests, confirming their validity. Meanwhile, the examination of policy mechanisms reveals that public environmental awareness, government environmental regulation, and corporate environmental information disclosure are three key policy transmission mechanisms through which LCUP affects corporate green innovation. The findings of this study provide significant empirical insights for addressing climate change and enhancing the sustainable capacity of urban environments.

Keywords: low-carbon urban policy; corporate green innovation; climate change; DID; environmental sustainability

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1. Introduction

Mitigating and adapting to global warming, as well as reducing carbon dioxide emissions, have become a worldwide political consensus and pressing global issues. Currently, over 130 countries and regions have committed to achieving 'zero carbon' and 'carbon neutrality' goals, including China's 'dual-carbon' target set in 2020. This goal aims to peak carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060 [1]. Despite China's remarkable economic growth since reform and opening up, it has also faced challenges of high input, consumption, and pollution. China's carbon dioxide emissions were projected to reach 12.6 billion tons in 2023, representing 33.69% of global emissions, more than double those of the United States, the world's second-largest emitter. Accelerating the establishment of a 'dual-carbon' policy framework and achieving the 'dual-carbon' target is not only China's responsibility in addressing global climate change but also essential for advancing green, low-carbon practices and promoting high-quality development.

Even before the formal proposal in 2020 of the 'dual-carbon' target, China had already integrated the control of greenhouse gas emissions and the achievement of a green and low-carbon economic and social transformation into its national economic and social development plans for the medium and long term. The country had also initiated demonstration projects of low-carbon cities at the urban level. This emphasis on cities has been due to their role as hubs of economic and social activities, responsible for over 80% of China's resource consumption and greenhouse gas emissions. China's low-carbon pilot cities have undergone three rounds of approvals since their selection in 2010, currently encompassing 78 cities, two counties, and one region across six provinces. The framework for the LCUP is designed to guide cities towards more environmentally friendly and sustainable development paths by reducing urban carbon emissions, advocating for green consumption, and fostering green innovation [2]. Low-carbon city building is already in full swing in international metropolises such as London and Tokyo. At the same time, as the core entities of urban economic activities, firms are not only crucial participants in the construction of low-carbon cities but also producers of greenhouse gas emissions and low-carbon environmental products [3]. In addition, green innovation within firms is considered one of the most effective approaches to achieving urban carbon emission reduction and urban sustainable development [4,5]. So, with China as a pioneer in promoting the construction of low-carbon cities, this study investigates whether green innovation can become an important catalyst for promoting energy saving and carbon reduction in enterprises.

In the processes of enterprises actively engaging in innovative activities, institutional policies play a crucial role in either promoting or inhibiting them. The efforts of enterprises to develop green products through technological innovation and to foster a low-carbon society have been significantly emphasized by the policies of low-carbon pilot cities. For instance, these pilot policies highlight that adjusting the industrial structure is the primary approach to reducing carbon emissions. This involves not only technologically transforming traditional industries for low-carbon upgrades but also encouraging the transformation and adjustment of industrial structures, implementing cleaner production practices, and actively developing low-carbon energy sources. The national low-carbon pilot cities have been in operation for several years, expanding their reach and influence, and have emerged as key regional innovation policy pilots that significantly impact urban green innovation. Therefore, as a critical progressive reform policy in China's implementation of an innovation-driven development strategy, has the establishment of national low-carbon pilot cities effectively promoted green innovation among enterprises? What is the underlying impact mechanism? Are there variations in the outcomes of green innovation across different cities? These questions are not only theoretical but also require empirical testing.

In light of this, this study attempts to examine the impact of the low-carbon urban pilot policy on corporate green innovation by applying a multi-period DID approach, utilizing lists of low-carbon city pilot projects announced by China in 2010, 2012, and 2017, along with data from companies listed on the Shanghai and Shenzhen A-share markets. It aims to explore the pathways through which this pilot policy influences firms' green innovation efforts, providing valuable suggestions and insights for reducing urban carbon emissions, promoting green innovation within firms, and advancing urban sustainable development.

2. Literature Review

The existing literature assessing the impact of China's LCUP and corporate green innovation is summarized as follows.

The literature assessing the effects of LCUP is relatively well established. Overall, it encompasses the economic, environmental, and social impacts of the policies. From an economic perspective, scholars suggest that low-carbon city policies have spurred economic growth [6,7] and industrial transformation [8,9]. In terms of environmental effects, these policies are believed to have reduced greenhouse gas emissions [10,11], enhanced energy efficiency [12,13], and improved air quality [14,15]. Socially, scholars have identified a significant influence of low-carbon city policies on public environmental awareness [16,17].

The literature about the factors influencing corporate green innovation is also relatively well developed. Regarding internal factors, scholars have identified elements such as organizational culture and leadership [18–20], knowledge and skills [21,22], allocation of organizational resources [23], organizational structure and processes [24,25], and internal incentive mechanisms [26]. These internal factors interact with each other, jointly determining a company's willingness and ability to engage in green innovation. As for external factors, researchers believe that the external influences on corporate green innovation include government policies and regulations [27,28], market demand [29], technological development, competitive pressure, societal pressure [30], and financial institutions [31]. These external factors interact with each other, collectively affecting a company's green innovation decisions and practices.

Research examining the impact of LCUP on green innovation has also occupied the attention of scholars. Chen et al. investigated the impact of LCUP on levels of green innovation from an urban perspective, finding that pilot policies significantly promoted urban green innovation, with the presence of heterogeneity in this impact [32]. Zhang et al. not only discovered that LCUP facilitated urban green innovation but also identified a spatial spillover effect of such policy impacts [33]. He et al. conducted a study on a dataset of 276 Chinese cities, revealing that technological innovation, industrial upgrading, and the capability of public services are significant mechanisms through which LCUP affected the level of urban green innovation [34]. Gao et al. employed the difference-in-differences (DID) model to explore the impact of LCUP on green total factor productivity, finding that green innovation and industrial structure upgrading are key mechanisms through which pilot policies exert their effects [35]. However, overall, much of the current research has focused on the macro and meso effects of LCUP, with less attention given to the micro effects, particularly the impact of low-carbon city policies on corporate green innovation from a micro perspective. In addition, a few studies have explored the mechanisms through which LCUPs affect green innovation, but there is a lack of mechanism analysis research from the perspectives of public environmental concern, the intensity of government environmental regulation, and corporate environmental information disclosure. Hence, the analysis of heterogeneity at the corporate and city levels regarding the impact of LCUP needs to be strengthened in depth and at the systemic level.

Compared with the existing research, the marginal contributions of this paper are as follows: (1) Utilizing empirical data from China, it tests the impact of LCUP on corporate green innovation, enriching the study of the micro effects of low-carbon city policies and expanding the literature on factors influencing corporate green innovation. (2) It analyzes and verifies the mechanisms through which LCUP affects corporate green innovation from the perspectives of public environmental concern, government environmental regulation, and corporate environmental information disclosure, thereby broadening the research on the channels through which LCUP influences corporate green innovation. (3) Examining the heterogeneous impacts of LCUP on corporate green innovation at both urban and corporate levels, it provides more specific insights for government departments to formulate targeted policy recommendations.

3. Policy Background and Mechanism Analysis

3.1. Policy Background

To further control greenhouse gas emissions, primarily carbon dioxide, and promote urban low-carbon development, China's National Development and Reform Commission (NDRC) issued a notice on 19 July 2010 regarding initiating pilot work for low-carbon provinces and cities. This notice marked the start of the low-carbon city pilot policy across the country, with the first batch of pilot areas covering five provinces and eight cities. In April 2012, to implement the "Twelfth Five-Year Plan for Controlling Greenhouse Gas Emissions" issued by the State Council and to further promote the construction of low-carbon cities, the NDRC's Climate Department further identified the second batch of low-carbon city pilots, which was expanded to include one province and twenty-eight cities. Subsequently, in 2017, the third batch of pilot cities was established, involving 48 cities. With this, the LCUP began to be implemented nationwide in China.

The LCUP encompasses various aspects of urban low-carbon and green development, including industrial restructuring, energy consumption control, promotion of green consumption, planning of green buildings, and implementation of green transportation. For instance, the policy specifies the acceleration of low-carbon technology innovation and the transformation of traditional industries to build an industrial system characterized by low carbon emissions. It aims to promote low-carbon consumption and lifestyles through the widespread use of low-carbon products and the promotion of low-carbon living concepts. Additionally, the policy seeks to create a favorable environment for the construction of low-carbon cities by implementing a greenhouse gas emission control target responsibility system, establishing a carbon emission market mechanism, and encouraging corporate green innovation. In terms of carbon emission reduction outcomes, the LCUP, which has been in place since 2010, has already achieved significant results.

3.2. Policy Mechanism Analysis

(1) LCUP and Corporate Green Innovation

The low-carbon city pilot policy is a system that prioritizes energy saving and emission reductions. It aims to promote the overall decarbonization of urban development by improving energy efficiency, adjusting energy structure, and transforming the energy industry [36]. The goal is to enhance China's capacity for sustainable development, distinguishing it from other pilot policies at the city level. For instance, the pilot policy on intellectual property rights focuses on enhancing the city's ability to create, utilize, and protect intellectual property rights to promote regional knowledge innovation and improve the quality and efficiency of the regional economy [37]. On the other hand, the pilot policy on smart cities aims to revolutionize urban governance through information technology and achieve the intelligentization of urban management, services, and daily life [38].

It is well established that implementing low-carbon pilot policies can lead to significant reductions in corporate pollution, urban energy consumption, and carbon emissions [39]. These policies can utilize tools such as special funds, investment subsidies, loan subsidies, and incentives for low-carbon innovation to encourage enterprises to engage in green technological innovation and reduce production costs [40]. Through imposing policy constraints on outdated production processes, companies can be pushed towards low-carbon transformation, focusing on breakthroughs in low-carbon technologies and upgrades to a greener, low-carbon development model. This shift can drive the industrial sector towards an upgraded industrial structure and the formation of low-carbon industrial clusters [41]. Furthermore, creating a low-carbon ecosystem can enhance institutional mechanisms for low-carbon transformation, facilitate technological collaboration between industry, academia, and research institutions, create more opportunities for technological innovation, attract additional investments to spur economic development, and boost regional productivity [42]. Hence, we propose the following hypothesis:

H1. *The implementation of LCUP model cities positively impacts corporate green innovation.*

(2) Public Environmental Awareness and Corporate Green Innovation

Public awareness of environmental issues is a crucial driver of corporate green innovation [43]. Residents' low-carbon literacy and low-carbon consumption preferences are recognized as important engines for promoting the low-carbon transition of enterprises. The marketing strategies, product development, and other strategic decisions of companies are continuously influenced by the priorities of consumers, investors, policymakers, and the broader public. The heightened public focus on environmental issues is reflected in the pursuit of low-carbon lifestyles, the urgent demand for sustainable development, and preferences for green products and technologies [44]. These factors can provide companies with the motivation to increase their investments in research and development and to offer more environmentally friendly products and services.

LCUPs typically include various measures to reduce carbon emissions, such as promoting green buildings, enhancing energy efficiency, and encouraging the use of renewable energy [45]. The implementation of these policies can increase public awareness of environmental issues, enhance residents' low-carbon awareness, and cultivate low-carbon living habits and low-carbon consumption preferences, thereby encouraging companies to innovate in green ways. An increase in public environmental awareness can show companies the market demand for green products and technologies, guiding them to shift their innovation efforts towards environmental protection. On the other hand, increased public environmental awareness can also put pressure on companies by making them aware of the risks associated with not pursuing green innovation, such as damage to brand image or loss of market share [46]. Therefore, through implementing low-carbon city policies, the emphasis on environmental issues among the public can be enhanced, thereby driving companies to engage in green innovation. Hence, we propose the further hypothesis:

H2. *The LCUP promotes corporate green innovation by enhancing public environmental awareness.*

(3) Government Environmental Regulation and Corporate Green Innovation

Low-carbon city pilot policies have enhanced carbon emission management in pilot regional governments and improved the carbon emission target responsibility system [47]. Governments in low-carbon pilot regions typically establish carbon emission big data platforms, standardize carbon emission accounting and management systems, create carbon emission responsibility lists, and define carbon emission standards for different industries. This enables them to access real-time data on carbon emissions from enterprises, enhance supervision and accountability, and implement stricter low-carbon and environmental protection regulations [48]. The intensification of government environmental regulation, including stringent environmental laws, precise emission standards, and hefty fines for non-compliance, exerts pressure on companies, compelling them to seek new methods to reduce pollution emissions [49]. Under strict environmental regulation, companies that fail to innovate in green technologies may face fines, production restrictions, or even the risk of closure. This regulatory pressure can stimulate corporate innovation, encouraging companies to innovate in production technologies, improve product design, and enhance product quality. Additionally, government environmental regulation can motivate green innovation by setting environmental standards, providing clear innovation targets, offering technical guidance, and rewarding green innovations. This not only helps companies to determine their R&D direction but also fosters a level playing field, allowing those that have achieved green innovation to thrive. Hence, we propose the following hypothesis:

H3. *The LCUP promotes corporate green innovation through the strengthening of government environmental regulation.*

(4) Corporate Environmental Information Disclosure and Corporate Green Innovation

Corporate environmental information disclosure is a significant factor driving green innovation [50]. Environmental information disclosure is a crucial strategy for enterprises to fulfill their environmental responsibilities, address market failures due to information asymmetry, facilitate government efforts in modernizing environmental governance, and support initiatives for carbon peaking and neutrality. Through providing stakeholders with accurate and comprehensive environmental data, disclosure enhances market efficiency in allocating environmental resources, promotes research and adoption of green technologies, and fosters third-party markets for solutions to environmental pollution problems [51]. Moreover, it strengthens social cohesion, helps consumers make informed choices about green products, and improves public oversight of pollution emissions via encouraging a shift towards green practices across society.

Low-carbon city policies require companies to publicly disclose information such as their pollution emissions, energy consumption, and environmental action plans. This disclosure allows the public, investors, and policymakers to understand and evaluate a company's environmental performance and to hold it accountable [52]. Additionally, disclosure of environmental information can increase competitive pressure among companies, encouraging them to adopt more environmentally friendly technologies and methods. For those companies that excel in environmental performance, information disclosure can also help them win market trust and gain a competitive edge. Furthermore, an increase in environmental information disclosure significantly reduces the opportunities for companies to engage in polluting activities, increases the cost of environmental non-compliance, and forces companies to devote more effort to regulating and correcting their business activities, thereby promoting green innovation [53]. Hence, we propose the following hypothesis:

H4. *The LCUP promotes corporate green innovation by increasing corporate environmental information disclosure.*

4. Research Design

4.1. Basic Model Setting

This study employed a fixed-effects double-difference approach to evaluate the influence of low-carbon demonstration city construction on corporate green innovation. Out of the 234 cities sampled, 78 were designated as low-carbon pilot demonstration cities between 2005 and 2020, creating a quasi-natural experiment. The enterprises in these 78 cities served as the experimental group, while those in the remaining cities formed the control group. Through comparing these two groups, the study aims to determine the net impact of the national low-carbon pilot city policy on green innovation within enterprises, which could reduce estimation bias due to endogenous problems caused by environmental policies. Meanwhile, to address variations in the timing of city designations, the paper adopts the asymptotic double-difference method, building on prior work by Beck et al. (2010) and Liu et al. (2022) to assess the policy's effects [10,54]; the specific model setup is as follows:

$$Y_{ijt} = \gamma_0 + \gamma_1 Carbon\_Policy_{it} + \gamma_3 W_{ijt} + \rho_i + \sigma_j + \varphi_t + \varepsilon_{ijt} \quad (1)$$

where the dependent variable Y_{ijt} represents the green innovation capability of company j in city i in year t. The explanatory variable $Carbon\_Policy_{it}$ is a dummy variable indicating whether a low-carbon city policy was implemented in city i in year t, taking the value of 1 if the policy was implemented, and 0 otherwise. W_{ijt} represents a series of control variables that influence the effectiveness of the low-carbon city pilot policy.

In the estimation model under Equation (1), ρ_i represents city fixed effects, which control for disturbances caused by city characteristics that do not change over time. σ_j denotes firm-fixed effects, which control for disturbances caused by firm-specific characteristics that remain constant over time. φ_t indicates time-fixed effects, which control for disturbances caused by time-varying characteristics that do not vary across observed entities. ε_{ijt} refers to the model's random error term. To mitigate the potential heteroscedasticity issues in the data, in this study, standard errors have been clustered at the firm level.

The estimated coefficient γ_1 is the key observed coefficient for measuring the impact of LCUP. When γ_1 is greater than 0 and significantly positive, it indicates that LCUP has promoted corporate green innovation. Conversely, if γ_1 is less than 0 and significantly negative, it suggests that LCUP has reduced corporate green innovation. If the estimated coefficient γ_1 is not significant, it implies that LCUP has had no effect on corporate green innovation.

4.2. Variable Selection

(1) explained variables

Drawing on existing research, this study uses the number of green patent grants (*grantgreen*) as a proxy variable for corporate green innovation. Specifically, referring to the International Patent Classification (IPC) green inventory published by the World Intellectual Property Organization (WIPO) in 2010, the numbers of green patents granted to listed companies were identified. Additionally, considering the time lag in green patent authorization could impact the green innovation effects of LCUP, the number of green patent applications (*applygreen*) was used as an alternative proxy variable for corporate green innovation in robustness tests. This approach ensured the robustness of the baseline model regression results.

(2) explanatory variable

The core explanatory variable in this paper is the LCUP dummy variable, *Carbon_Policy*. This study treats the LCUP as a quasi-natural experiment. Interaction terms of city dummy variables and policy implementation time dummy variables were constructed to represent the policy treatment effect of low-carbon city policies. Specifically, if a city was designated as a low-carbon city in a given year, then *Carbon_Policy* was set to 1; otherwise, it was set to 0.

(3) control variables

Considering that factors related to cities and firms may introduce estimation errors in the impact on corporate green innovation, drawing from existing research [55–58], the following characteristic variables were selected as control variables for the baseline model: ① leverage ratio (*Lev*), expressed using total liabilities divided by total assets; ② company size (*Size*), expressed using the natural logarithm of total assets; ③ board size (*Board*), expressed using the natural logarithm of the number of people on the board; ④ return on equity (*ROE*), expressed using net profit divided by total assets; ⑤ Tobin's Q value (*TobinQ*), expressed using market capitalization divided by total assets; ⑥ asset turnover ratio (*ATO*), calculated using operating income divided by average total assets; ⑦ management shareholding ratio (*Mshare*), measured using the number of regulatory holdings divided by paid-in capital; ⑧ city-level environmental regulation (*envregul*), calculated according to the city's sulfur dioxide emissions.

(4) mechanism variables

Public environmental awareness was measured using the Baidu search index as a proxy variable. Specifically, accessing the Baidu search engine, setting the search location and timeframe with "environmental protection" as the search keyword, the frequency of mentions related to environmental protection for all prefecture-level cities was obtained using Python 3.12 software, leveraging web-crawling technology.

Government environmental regulation was categorized into three approaches: environmental penalties, environmental subsidies, and environmental certification. For environmental penalties, the number of environmental administrative cases accepted in the region served as the proxy variable. Environmental subsidies were represented by the amount of government environmental protection subsidies received by listed companies. Environmental certification was determined according to whether a listed company had obtained International Organization for Standardization 14001 (ISO14001) environmental certification.

Corporate environmental information disclosure varies in intensity and can be conducted by listed companies in three ways: ① disclosing environmental information in the company's annual report; ② disclosing environmental information in the corporate social responsibility (CSR) report; ③ issuing a separate environmental report for disclosing environmental information. Based on these methods, this study adopts them as three proxy variables for corporate environmental information disclosure.

(5) other variables

Cities were classified according to their economic geographic region into three areas: Eastern, Central, and Western regions.

Based on the nature of the controlling shareholder, companies were categorized into state-owned enterprises and non-state-owned enterprises.

Cities' green finance level was assessed drawing on existing research, utilizing data on green credit, green insurance, green investment, and green bonds across regions. The entropy method was used to calculate the green finance index for each prefecture-level city, serving as the proxy variable for the city's green finance level.

Corporate media attention was measured according to the total number of headlines reported by online financial news media, as recorded in the database of financial news for Chinese listed companies.

Corporate digital transformation was assessed by referencing existing research, and Python 3.12 software was used to extract and count the frequency of key digital transformation-related keywords in the annual reports of listed companies. The frequency of these keywords served as the proxy variable for measuring the extent of a company's digital transformation.

4.3. Data Description

The sample for the baseline model of this study spanned from 2005 to 2020 and consisted of unbalanced panel data. City-level data were sourced from the *China City Statistical Yearbook* and the *China Statistical Yearbook*, while firm-level data were taken from the CSMAR (China Stock Market and Accounting Research) database. Data on listed companies' green patents were obtained from the National Intellectual Property Administration. For data processing, missing values were imputed using linear interpolation based on information from local government websites and statistical bulletins. Descriptive statistics for the main variables of the study are presented in Table 1.

Table 1. Descriptive statistics of main variables.

Variables	(1) N	(2) Mean	(3) SD	(4) Min	(5) Max
Size	28,958	22.0715	1.3879	10.8422	28.6365
Lev	28,958	0.4642	1.5978	−0.1947	178.3455
ROE	28,712	0.0604	0.4721	−60.1534	21.3477
ATO	28,959	0.6721	0.5613	0.0000	12.3729
Board	28,957	2.1352	0.2016	0.6931	2.8904
TobinQ	28,345	2.3146	12.0818	0.6735	1752.7050
Mshare	27,984	0.1360	0.2648	0.0000	20.1708
grantgreen	28,960	0.6569	1.0247	0.0000	6.8997
applygreen	28,960	0.8681	1.2072	0.0000	7.3639
envregul	28,691	9.9902	1.5442	0.6931	13.3491

5. Empirical Analysis

5.1. Baseline Regression Model

Table 2 presents the model regression results regarding the impact of LCUP on corporate green innovation. Column (1) shows the model estimation results without controlling for fixed effects and without including control variables. Column (2) displays the model estimation results without adding control variables but controlling for fixed effects. Columns (3) and (4) provide the model estimation results after gradually controlling for fixed effects with the inclusion of control variables.

According to the model results reported in Table 2, the regression coefficients for the LCUP (*Carbon_Policy*) across columns (1) to (4) were 0.3714, 0.0405, 0.1636, and 0.0616, respectively, all of which passed the significance tests. This indicates that, on one hand, the size of the regression coefficient for *Carbon_Policy* changed, suggesting that city characteristics, firm-specific variables, and time effects influenced the estimated results of the low-carbon city policy effect. Therefore, it was necessary to include control variables and control for fixed effects. On the other hand, the significance of the regression coefficient for *Carbon_Policy* remained unchanged, indicating that the model's estimated results for the effect of low-carbon city policies are robust. Consequently, LCUP can significantly promote corporate green innovation.

Table 2. Baseline regression estimates.

Variables	(1) Grantgreen	(2) Grantgreen	(3) Grantgreen	(4) Grantgreen
Carbon_Policy	0.3714 ***	0.0405 **	0.1636 ***	0.0616 ***
	(27.0865)	(2.1113)	(11.6186)	(3.0785)
TobinQ			0.0058 **	0.0041 ***
			(2.3809)	(3.1495)
Mshare			0.1754 **	−0.0319 ***
			(2.1765)	(−2.7935)
ROE			0.0092	0.0095
			(0.6047)	(0.6929)
ATO			0.0001	−0.0422 ***
			(0.0043)	(−2.6135)
Size			0.3950 ***	0.3209 ***
			(49.3391)	(25.4347)
Lev			−0.1142 ***	0.0320
			(−2.8733)	(0.7082)
Board			−0.0863 **	0.0281
			(−2.3009)	(0.6791)
envregul			−0.0755 ***	0.0079
			(−16.1234)	(0.8120)
Constant	0.6594 ***	0.8460 ***	−6.9883 ***	−6.3732 ***
	(72.5653)	(74.1767)	(−35.6614)	(−21.2683)
City FE	NO	YES	NO	YES
Year FE	NO	YES	NO	YES
Firm FE	NO	YES	NO	YES
Observations	28,960	28,403	26,956	26,425
R-squared	0.0233	0.7330	0.2071	0.7489

Notes: ***, ** represent regression coefficients that pass the test of significance at the 1%, 5%, respectively. Values in () are t-statistics.

5.2. Robustness Test

5.2.1. Parallel Trend Test

The premise of using a multi-period DID model is that there are no significant differences between the experimental and control groups before the implementation of the policy, satisfying the parallel trend assumption. Table 3 reports the test results for the parallel trend assumption regarding the LCUP. "policy_year" refers to the relative year of policy occurrence, with "pre*" indicating the relative time before the policy implementation, "post*" indicating the relative time after the policy implementation, and "current" referring to the base period of the policy occurrence. "policy_test" refers to the policy effect test coefficient.

Table 3. Parallel trend test.

Policy_Year	Policy_Test	Policy_Year	Policy_Test
pre4	−0.0550	*post3*	0.0380
	(−1.5599)		(1.0252)
pre3	0.0039	*post4*	0.0877 **
	(0.0975)		(2.4258)
pre2	0.0003	*post5*	0.1287 ***
	(0.0087)		(3.2433)
current	0.0263	*post6*	0.0601
	(0.7517)		(1.4712)
post1	−0.0191	*post7*	0.0932 **
	(−0.5513)		(2.3117)
post2	0.0605 *	*post8*	0.0860 **
	(1.6963)		(1.9799)

Table 3. *Cont.*

Policy_Year	Policy_Test	Policy_Year	Policy_Test
Constant	0.8184 *** (29.0115)	Constant	0.8184 *** (29.0115)
Observations	28,403	Observations	28,403
R-squared	0.7333	R-squared	0.7333

Notes: ***, ** and * represent regression coefficients that pass the test of significance at the 1%, 5% and 10% levels, respectively. Values in () are t-statistics.

According to Table 3, before the base period of policy occurrence, the policy effect test coefficients were insignificant and negative. This means that there were no significant differences between the control and experimental groups before the implementation of the low-carbon city policy, indicating that the research sample for this experiment passed the parallel trend assumption test.

5.2.2. Placebo Test

To eliminate potential biases in the estimation results caused by the randomness of policy timing changes and policy sample settings, this study included a placebo test. Specifically, the implementation times for environmental protection-type city policies were set randomly and the trial area city samples for LCUP were randomly selected for both random policy timing and random policy city sample placebo tests. Additionally, the bootstrap method was employed to repeat the randomization process 500 times and the model estimation results were then derived. Kernel density distribution plots of the estimated coefficients for the impact of LCUP on corporate green innovation are presented in Figures 1 and 2.

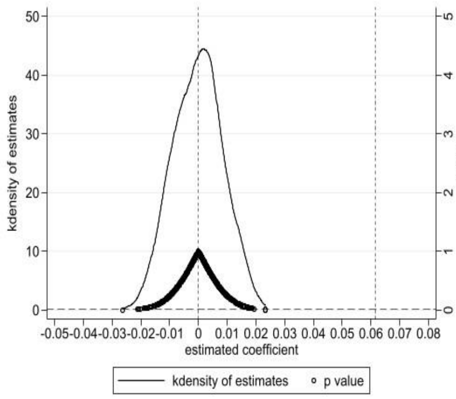

Figure 1. Random city sample placebo test.

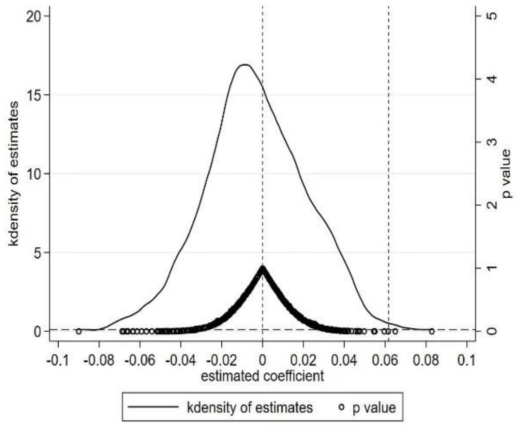

Figure 2. Random policy timing placebo test.

As shown in Figures 1 and 2, the estimated coefficients followed a normal distribution, with the mean of the coefficients close to 0 and not significant. At the same time, the true estimated coefficient of the LCUP (0.0616) was within the low-probability range of the coefficient kernel density plot of the placebo test results. This indicates that the impact of LCUP on corporate green innovation is not a result of chance. Therefore, even after eliminating the interference of policy timing and policy sample factors, the conclusions of this study remain robust.

5.2.3. PSM-DID

Given that the inclusion of companies' cities into the low-carbon city list is not entirely random, to further mitigate sample selection bias and address endogeneity in the model, we applied the propensity-score-matching–difference-in-differences (PSM-DID) method to re-estimate the baseline model. Specifically, we first selected eight characteristic variables as matching variables for sample matching: leverage ratio, company size, board size, return on equity, Tobin's Q value, asset turnover ratio, management shareholding ratio, and city-level environmental regulation. Next, adopting a period-by-period matching approach, we re-matched the samples using three methods: kernel matching, K-nearest-neighbor matching, and radius matching. Finally, we re-estimated the multi-period DID model for the three types of matched samples obtained. The PSM-DID estimation results are presented in Table 4.

Table 4. Robustness test results based on PSM-DID.

Variables	**(1)** **K-Nearest-Neighbor Matching**	**(2)** **Radius Matching**	**(3)** **Kernel Matching**
Carbon_Policy	0.0569 **	0.0577 ***	0.0564 ***
	(2.1355)	(2.9956)	(2.9390)
TobinQ	0.0045	0.0078 ***	0.0040 ***
	(1.3700)	(3.2864)	(3.2539)
Mshare	−0.0292 ***	−0.0300 ***	−0.0311 ***
	(−2.8355)	(−2.5933)	(−2.7011)
ROE	0.0213	0.0171	0.0094
	(1.2592)	(0.9031)	(0.7122)
ATO	−0.0483 **	−0.0543 ***	−0.0485 ***
	(−2.0697)	(−3.1796)	(−3.0345)
Size	0.2789 ***	0.3191 ***	0.3144 ***
	(16.8115)	(25.4375)	(26.0636)
Lev	−0.0356	0.0205	0.0302
	(−0.5952)	(0.4534)	(0.6874)
Board	−0.0019	0.0221	0.0246
	(−0.0362)	(0.5510)	(0.6150)
envregul	0.0349 **	0.0129	0.0114
	(2.4332)	(1.3327)	(1.2009)
Constant	−5.7635 ***	−6.3796 ***	−6.2637 ***
	(−14.3474)	(−21.2944)	(−21.7607)
City FE	YES	YES	YES
Year FE	YES	YES	YES
Firm FE	YES	YES	YES
Observations	16,169	27,177	27,489
R-squared	0.7126	0.7433	0.7435

Notes: ***, ** represent regression coefficients that pass the test of significance at the 1%, 5% levels, respectively. Values in () are t-statistics.

Columns (1), (2), and (3) of Table 4 report the PSM-DID model estimation results using the K-nearest-neighbor matching, radius matching, and kernel matching methods, respectively. The results show that the coefficient estimates for *Carbon_Policy* were 0.0569, 0.0577, and 0.0564, respectively, all of which passed the significance test at least at the 5% level. It can be observed that these model estimation results are essentially consistent with the baseline model estimates. Therefore, after further mitigating the endogeneity problem caused by sample selection, the conclusions of this study remain robust, indicating that the LCUP significantly promotes the enhancement of corporate green innovation.

5.2.4. Other Robustness Testing

To further ensure the robustness and reliability of the results, this study conducted the following three robustness checks: ① **Trimming the tails of the sample**. To avoid biases in model estimation due to extreme values in the sample, we performed 1% tail trimming on the research sample and then re-estimated the baseline model; ② **Replacing the dependent variable**. Given the time lag in patent authorization, using the number of green patent grants as the dependent variable may have introduced errors in the estimation of policy effects. Replacing it with the number of green patent applications can effectively mitigate this endogeneity issue. Therefore, this study used the number of green patent applications as the dependent variable in the baseline model for re-estimation. ③ **Adding omitted variables**. Considering that characteristics such as a city's level of economic development, industrial structure, and population size may have an endogenous impact on corporate green innovation, in order to mitigate estimation errors, we added three control variables to the baseline model: city economic development level (*economy*), industrial structure (*industry*), and population size (*population*). The results of these three robustness checks are presented in Table 5.

Table 5. Other robustness tests.

Variables	(1) Trimming Sample Tail	(2) Replacing Dependent Variable	(3) Adding Omitted Variable
Carbon_Policy	0.0578 ***	0.0531 **	0.0621 ***
	(2.8992)	(2.3355)	(3.0726)
TobinQ	0.0114 **	0.0028 ***	0.0041 ***
	(2.5338)	(3.1853)	(3.1963)
Mshare	−0.0270	−0.0277 ***	−0.0319 ***
	(−0.4489)	(−2.8339)	(−2.7877)
ROE	0.0185	−0.0017	0.0095
	(0.4342)	(−0.1392)	(0.6950)
ATO	−0.0506 **	−0.0659 ***	−0.0421 ***
	(−2.1876)	(−4.5329)	(−2.6059)
Size	0.3234 ***	0.2202 ***	0.3219 ***
	(24.2897)	(20.5194)	(25.4602)
Lev	0.0397	0.1143 ***	0.0286
	(0.8492)	(2.9350)	(0.6308)
Board	0.0313	−0.0652 *	0.0286
	(0.7481)	(−1.7782)	(0.6916)
envregul	0.0127	−0.0025	0.0081
	(1.2517)	(−0.3060)	(0.8308)
population			−0.0063
			(−0.1970)
economy			−0.0261
			(−0.8306)
industry			−0.0012
			(−0.6565)
Constant	−6.5026 ***	−4.0524 ***	−6.0101 ***
	(−20.4165)	(−15.8023)	(−11.3907)
City FE	YES	YES	YES
Year FE	YES	YES	YES
Firm FE	YES	YES	YES
Observations	26,425	26,425	26,405
R-squared	0.7405	0.7412	0.7488

Notes: ***, ** and * represent regression coefficients that pass the test of significance at the 1%, 5% and 10% levels, respectively. Values in () are t-statistics.

Columns (1), (2), and (3) of Table 5, respectively, present the regression estimation results for the three robustness checks: sample tail trimming, replacing the dependent variable, and adding omitted variables. From Table 5, it can be observed that the size, direction, and significance of the *Carbon_Policy* coefficient under the three robustness test methods are essentially consistent with the original baseline model. This indicates that the conclusions of this study are robust, meaning that low-carbon city policies have a significant policy effect on corporate green innovation.

6. Heterogeneity Analysis

6.1. Urban Regional Heterogeneity

To examine whether the effects of the LCUP differ among enterprises across various regions, this study categorized enterprise samples based on China's geographical and economic regional division into Eastern, Central, and Western regions. Subgroup regression tests were then performed to assess the policy effects within these regions. The estimated results are provided in Table 6.

Table 6. Urban regional heterogeneity estimates.

Variables	(1) East	(2) Central	(3) West
Carbon_Policy	0.0703 **	0.1260 ***	0.0026
	(2.4604)	(2.5893)	(0.0578)
TobinQ	0.0052 **	0.0110 **	0.0030 ***
	(2.2609)	(2.5381)	(3.0634)
Mshare	−0.0241	−0.0250 ***	−0.3972
	(−0.4056)	(−3.0099)	(−1.5161)
ROE	0.0311	−0.0011	−0.0085
	(1.3559)	(−0.0364)	(−0.5478)
ATO	−0.0661 ***	0.0262	−0.0381
	(−3.5250)	(0.6364)	(−0.5694)
Size	0.3381 ***	0.3370 ***	0.2285 ***
	(22.0686)	(11.1007)	(6.9906)
Lev	0.0110	0.1321	0.0754
	(0.1963)	(1.1738)	(0.7204)
Board	0.0211	0.1528	−0.1693
	(0.4295)	(1.5050)	(−1.3903)
envregul	0.0151	−0.0340	−0.0271
	(1.3427)	(−0.9065)	(−0.9322)
Constant	−6.7624 ***	−6.7416 ***	−3.6633 ***
	(−18.5521)	(−8.8221)	(−4.6850)
City FE	YES	YES	YES
Year FE	YES	YES	YES
Firm FE	YES	YES	YES
Observations	19,043	4138	3229
R-squared	0.7629	0.7057	0.7016

Notes: ***, ** represent regression coefficients that pass the test of significance at the 1%, 5% levels, respectively. Values in () are t-statistics.

In Table 6, columns (1), (2), and (3), respectively, show the estimated impacts of LCUP on corporate green innovation in the Eastern, Central, and Western regions. For the sample of enterprises in the Eastern region, the coefficient estimate of *Carbon_Policy* is 0.0703, significant at the 5% level. In the Central region sample, the *Carbon_Policy* coefficient estimate is 0.1260, passing the significance test at the 1% level. In the Western region sample, the coefficient estimate of *Carbon_Policy* is 0.0026, and the model estimation is not significant. This indicates that the LCUP has significantly promoted green innovation in enterprises located in the Eastern and Central regions but has not had a significant effect on green innovation in Western regional enterprises. According to the model estimates, LCUP has enhanced green innovation in Eastern enterprises by approximately 7% and in Central region enterprises by 12.6%, while it did not significantly enhance green innovation in Western regional enterprises. The possible reasons for this result are that the Western region has lagged behind in economic development compared to the East and Center, with less emphasis on environmental issues. The East and Center have more advanced green technology, abundant green talent, and stricter environmental technology standards, giving them a first-mover advantage in green technology innovation. Consequently, the environmental protection-oriented sustainable urban development policy has not significantly impacted green innovation in Western regional enterprises.

6.2. Heterogeneity of Corporate Property Ownership

To explore whether the impact of LCUP on corporate green innovation varies with the ownership characteristics of enterprises, this study categorized the enterprise samples into state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs). A heterogeneity test was then conducted on the data for policy effects across different ownership types. The regression results are presented in Table 7.

Table 7. Corporate property ownership heterogeneity estimates.

Variables	**(1)** **Non-SOEs**	**(2)** **SOEs**
Carbon_Policy	0.1064 ***	0.0095
	(3.9101)	(0.3093)
TobinQ	0.0042 ***	0.0050
	(2.9803)	(1.0891)
Mshare	−0.0495 ***	−0.2970
	(−3.1424)	(−0.6019)
ROE	0.0086	0.0197
	(0.3997)	(1.0581)
ATO	−0.0737 ***	−0.0139
	(−3.8902)	(−0.4187)
Size	0.3274 ***	0.3330 ***
	(19.5937)	(14.8653)
Lev	0.1568 ***	−0.1016
	(2.7833)	(−1.2301)
Board	0.0749	−0.0829
	(1.3895)	(−1.2248)
envregul	0.0039	0.0046
	(0.3026)	(0.2912)
Constant	−6.5691 ***	−6.3882 ***
	(−16.6861)	(−11.7165)
City FE	YES	YES
Year FE	YES	YES
Firm FE	YES	YES
Observations	16,528	9832
R-squared	0.7140	0.8035

Notes: ***, represent regression coefficients that pass the test of significance at the 1%, levels, respectively. Values in () are t-statistics.

Table 7, columns (1) and (2) display the estimated coefficient results of the impact of LCUP on green innovation for non-state-owned enterprises and state-owned enterprises, respectively. In the sample of state-owned enterprises, the estimated coefficient for *Carbon_Policy* was 0.0095, which was not significant. In the sample of non-state-owned enterprises, the estimated coefficient for *Carbon_Policy* was 0.1064, and the model estimation result was significant at the 1% level. It is evident that low-carbon city policies have enhanced green innovation in non-state-owned enterprises by approximately 10.64%, while having no significant effect on green innovation in state-owned enterprises. The difference in size between state-owned enterprises and non-state-owned enterprises may explain why the latter tend to have a quicker response to market changes and a keener interest in green technology. Additionally, non-state-owned enterprises often experience higher pressure from environmental regulations, prompting them to expedite research and development in green technology to foster innovation within their organizations.

6.3. Heterogeneity of Urban Green Finance

To investigate whether the impact of LCUP on corporate green innovation varies across regions with different levels of green finance, this study categorized the enterprises based on the level of green finance in their respective regions into two groups: enterprises from regions with high levels of green finance and enterprises from regions with low levels of green finance. Subsequently, subgroup regression tests were conducted to examine the heterogeneity of policy impacts between these groups. The estimated results are presented in Table 8.

Table 8. Urban green finance heterogeneity estimates.

Variables	(1) High Green Finance	(2) Low Green Finance
Carbon_Policy	0.0573 **	0.1404
	(2.4014)	(1.5230)
TobinQ	0.0032 ***	0.0085 **
	(2.8456)	(2.4516)
Mshare	−0.0326 ***	0.0985
	(−3.3132)	(1.0514)
ROE	0.0132	0.0055
	(0.9731)	(0.1583)
ATO	−0.0271	−0.0423 *
	(−1.0989)	(−1.8433)
Size	0.3086 ***	0.3333 ***
	(16.3282)	(16.0495)
Lev	−0.0310	0.0335
	(−0.4653)	(0.4470)
Board	0.0005	0.0622
	(0.0085)	(0.9344)
envregul	0.0048	0.0043
	(0.2875)	(0.2490)
Constant	−6.0930 ***	−6.6765 ***
	(−13.4122)	(−13.3430)
City FE	YES	YES
Year FE	YES	YES
Firm FE	YES	YES
Observations	12,794	13,082
R-squared	0.7040	0.8175

Notes: ***, ** and * represent regression coefficients that pass the test of significance at the 1%, 5% and 10% levels, respectively. Values in () are t-statistics.

Columns (1) and (2) of Table 8 respectively show the model regression results for the impact of LCUP on corporate green innovation in regions with high and low levels of green finance. It was calculated that in the sample group of enterprises from regions with high levels of green finance, the regression coefficient for *Carbon_Policy* was 0.0573, significant at the 5% level. In contrast, for enterprises in regions with low levels of green finance, the regression coefficient for *Carbon_Policy* was 0.1404, but this did not pass the significance test. In other words, the LCUP has promoted green innovation in enterprises located in regions with high levels of green finance, while it has had no significant effect on enhancing green innovation in enterprises from regions with low levels of green finance. According to the model results, the LCUP has facilitated an approximate 5.73% enhancement in green innovation for enterprises in regions with high levels of green finance. This result may be attributed to the presence of high levels of green finance in certain regions, providing enterprises with easier access to green resources like technology, capital, and talent. This access ultimately helps reduce the risks and costs associated with green innovation, leading to an acceleration in the pace of green innovation within these enterprises.

6.4. Heterogeneity of Corporate Media Attention

To examine whether the impact of low-carbon city policies on corporate green innovation varies with different levels of media attention, this study categorized the sample enterprises into groups of high media attention and low media attention. The regression estimation results for the impact of LCUP on green innovation in enterprises with varying levels of media attention are presented in Table 9.

Table 9. Corporate media attention heterogeneity estimates.

Variables	**(1)** **Low Media Attention**	**(2)** **High Media Attention**
Carbon_Policy	0.0072	0.1128 ***
	(0.2480)	(3.1550)
TobinQ	0.0082 ***	0.0032 ***
	(5.3490)	(4.3338)
Mshare	0.0106	−0.0342 ***
	(0.1316)	(−3.4460)
ROE	−0.0257	0.0423 **
	(−1.2758)	(2.1925)
ATO	0.0080	−0.0710 ***
	(0.3364)	(−2.9439)
Size	0.3395 ***	0.3048 ***
	(17.1374)	(14.6663)
Lev	0.0988	−0.0781
	(1.4785)	(−1.0511)
Board	0.0033	0.0802
	(0.0497)	(1.2810)
envregul	0.0109	0.0116
	(0.8045)	(0.6848)
Constant	−6.8167 ***	−6.0999 ***
	(−14.9886)	(−12.0022)
City FE	YES	YES
Year FE	YES	YES
Firm FE	YES	YES
Observations	13,118	12,612
R-squared	0.7066	0.8115

Notes: ***, ** represent regression coefficients that pass the test of significance at the 1%, 5% levels, respectively. Values in () are t-statistics.

Table 9 shows that for enterprises with low media attention, the coefficient estimate of *Carbon_Policy* was 0.0072, and the regression model was not significant. In contrast, for enterprises with high media attention, the coefficient of *Carbon_Policy* was 0.1128, passing the significance test at the 1% level. This indicates that LCUP does not enhance green innovation in enterprises with low media attention, but significantly promotes green innovation in enterprises with high media attention. It is evident that the effect of low-carbon city policies on enhancing green innovation in enterprises with high media attention was approximately 11.28%. Enterprises that receive high media attention are often influenced by public opinion and are more likely to face environmental regulations. This increased scrutiny makes it more difficult for them to violate environmental regulations without consequences, leading them to invest more in green innovations. Additionally, these enterprises can leverage their media attention to enhance their reputation and legitimacy through investing in green initiatives.

6.5. Heterogeneity in Enterprise Digitalization Level

To explore whether the impact of LCUP on corporate green innovation varies among enterprises with different levels of digitalization, this study divided the sample enterprises into groups based on their level of digitalization: low-level-digitalization enterprises and high-level-digitalization enterprises. Subsequently, subgroup regression tests were conducted. The model regression results for the impact of LCUP on green innovation in enterprises with different levels of digitalization are presented in Table 10.

Table 10. Enterprise digitalization Heterogeneity estimates.

Variables	(1) Low Digitalization	(2) High Digitalization
Carbon_Policy	0.0089	0.1165 **
	(0.3788)	(2.4182)
TobinQ	0.0025 ***	0.0094 ***
	(3.4488)	(3.1248)
Mshare	−0.2857 ***	−0.0091
	(−2.8990)	(−0.6258)
ROE	0.0032	−0.0106
	(0.2879)	(−0.3470)
ATO	−0.0474 *	−0.0545 ***
	(−1.8109)	(−2.6335)
Size	0.2340 ***	0.3765 ***
	(13.9820)	(16.1313)
Lev	−0.0594	−0.0087
	(−1.0409)	(−0.0998)
Board	0.0501	0.0517
	(0.9544)	(0.7444)
Envregul	−0.0111	0.0511 ***
	(−0.8381)	(3.0769)
Constant	−4.4454 ***	−7.8561 ***
	(−11.0521)	(−14.5676)
City FE	YES	YES
Year FE	YES	YES
Firm FE	YES	YES
Observations	13,184	12,784
R-squared	0.7261	0.8026

Notes: ***, ** and * represent regression coefficients that pass the test of significance at the 1%, 5% and 10% levels, respectively. Values in () are t-statistics.

According to Table 10, the regression coefficient for *Carbon_Policy* in the group of enterprises with a low level of digitalization was 0.0089, and the model result was not significant. In contrast, for the group of enterprises with a high level of digitalization, the estimated coefficient for *Carbon_Policy* was 0.1165, and the model passed the significance test at the 5% level. This indicates that low-carbon city policies have significantly enhanced green innovation in enterprises with a high level of digitalization, while having no significant effect on enhancing green innovation in enterprises with a low level of digitalization. From the coefficient value, it can be seen that the LCUP has enhanced green innovation in the high-level-digitalization group of enterprises by 11.65%. The possible reason for this result is that enterprises with higher levels of digitization benefit from increased communication channels for corporate information, leading to reduced transmission costs, operating expenses, and green innovation costs. Furthermore, their proficiency in data integration and information mining provides valuable support and advantages for green innovation and decision-making activities.

7. Mechanism Test

7.1. Public Environmental Awareness

Based on the mechanism analysis discussed earlier, low-carbon city policies can affect corporate green innovation through the mechanism of public environmental awareness.

Following existing research, this study used the environmental protection Baidu search index as the proxy variable for public environmental awareness (*Pubenv*). Specifically, by accessing the Baidu search engine, setting the search location and timeframe, and using "environmental protection" as the search keyword, this study obtained the frequency of mentions related to environmental protection for all prefecture-level cities.

The regression results for the public environmental awareness mechanism are shown in Table 11. The regression coefficient for *Carbon_Policy* × *Pubenv1* was 0.0005, and it passed the significance test at the 5% level. This indicates that the LCUP has promoted corporate green innovation through the mechanism of public environmental engagement. To further analyze whether there is heterogeneity in the sources of public environmental awareness, this study divided the Baidu search index into PC and mobile segments, to explore whether these represented heterogeneous effects of the public environmental awareness mechanism on corporate green innovation. According to columns (2) and (3) of Table 11, the coefficient estimate for *Carbon_Policy* × *Pubenv2* was 0.0009, passing the significance test at the 5% level, while the coefficient estimate for *Carbon_Policy* × *Pubenv3* was 0.0004, which failed to pass the significance test. This suggests that the mobile-based public environmental awareness mechanism has had a significant positive effect on corporate green innovation, whereas the PC-based mechanism has not had a significant promoting effect.

Table 11. Estimates of public environmental awareness mechanism.

Variables	**(1) Public Environmental Awareness**	**(2) Mobile**	**(3) PC**
Carbon_Policy × *Pubenv1*	0.0005 **		
	(1.8557)		
Carbon_Policy × *Pubenv2*		0.0009 **	
		(2.1127)	
Carbon_Policy × *Pubenv3*			0.0004
			(0.7012)
Carbon_Policy	0.0149	0.0299	0.0439
	(0.4667)	(1.2177)	(1.3414)
TobinQ	0.0041 ***	0.0041 ***	0.0041 ***
	(3.1419)	(3.1364)	(3.1497)
Mshare	−0.0321 ***	−0.0316 ***	−0.0322 ***
	(−2.8051)	(−2.7700)	(−2.8103)
ROE	0.0092	0.0093	0.0094
	(0.6641)	(0.6769)	(0.6803)
ATO	−0.0422 ***	−0.0420 ***	−0.0423 ***
	(−2.6136)	(−2.6008)	(−2.6181)
Size	0.3204 ***	0.3203 ***	0.3208 ***
	(25.3617)	(25.3561)	(25.4189)
Lev	0.0313	0.0307	0.0320
	(0.6938)	(0.6804)	(0.7099)
Board	0.0275	0.0287	0.0274
	(0.6657)	(0.6947)	(0.6635)
envregul	0.0148	0.0158	0.0092
	(1.4324)	(1.5176)	(0.9376)
Constant	−6.4351 ***	−6.4453 ***	−6.3846 ***
	(−21.3831)	(−21.3879)	(−21.3006)
City FE	YES	YES	YES
Year FE	YES	YES	YES
Firm FE	YES	YES	YES
Observations	26,425	26,425	26,425
R-squared	0.7489	0.7489	0.7489

Notes: ***, ** represent regression coefficients that pass the test of significance at the 1%, 5% levels, respectively. Values in () are t-statistics.

7.2. Government Environmental Regulation

Government environmental regulation plays a crucial role in influencing corporate green innovation. Generally, methods of government environmental regulation can be categorized into three types: environmental penalties, environmental subsidies, and environmental certification. Environmental penalties involve punitive measures through enforcement actions against corporate pollution activities. Environmental subsidies aim to reduce the cost of pollution treatment for enterprises, thereby correcting their pollution behaviors. Environmental certification incentivizes environmentally friendly practices through granting certifications and licenses to enterprises that meet environmental standards.

Accordingly, this study measured government environmental regulation from three aspects: environmental penalties (*Govregul1*), environmental subsidies (*Govregul2*), and environmental certification (*Govregul3*). Specifically, the number of regional environmental administrative penalty cases was used as the proxy variable for environmental penalties. Whether an enterprise received government environmental subsidies was used as the proxy variable for environmental subsidies. Whether an enterprise had passed ISO14001 environmental certification served as the proxy variable for environmental certification. The regression test results for the government environmental regulation mechanism are presented in Table 12.

Table 12. Estimates of government environmental regulation.

Variables	**(1) Environmental Penalties**	**(2) Environmental Subsidies**	**(3) Environmental Certification**
Carbon_Policy × *Govregul1*	0.0321 ***		
	(3.6334)		
Carbon_Policy × *Govregul2*		0.0213	
		(1.2995)	
Carbon_Policy × *Govregul3*			0.0447 **
			(2.2917)
Carbon_Policy	−0.2123 ***	0.0554 ***	0.0526 ***
	(−2.7712)	(2.7085)	(2.5831)
TobinQ	0.0041 ***	0.0042 ***	0.0041 ***
	(3.1440)	(3.1405)	(3.1447)
Mshare	−0.0303 ***	−0.0320 ***	−0.0316 ***
	(−2.6516)	(−2.7999)	(−2.7685)
ROE	0.0092	0.0095	0.0092
	(0.6784)	(0.6954)	(0.6742)
ATO	−0.0423 ***	−0.0424 ***	−0.0419 ***
	(−2.6175)	(−2.6277)	(−2.5990)
Size	0.3202 ***	0.3207 ***	0.3209 ***
	(25.4023)	(25.4096)	(25.4482)
Lev	0.0250	0.0322	0.0308
	(0.5549)	(0.7143)	(0.6836)
Board	0.0293	0.0275	0.0284
	(0.7083)	(0.6664)	(0.6876)
envregul	0.0082	0.0078	0.0079
	(0.8396)	(0.8010)	(0.8087)
Constant	−6.3647 ***	−6.3655 ***	−6.3738 ***
	(−21.2658)	(−21.2334)	(−21.2805)
City FE	YES	YES	YES
Year FE	YES	YES	YES
Firm FE	YES	YES	YES
Observations	26,425	26,425	26,425
R-squared	0.7490	0.7489	0.7489

Notes: ***, ** represent regression coefficients that pass the test of significance at the 1%, 5% levels, respectively. Values in () are t-statistics.

Columns (1), (2), and (3) of Table 12 respectively show the regression estimation results for the impact of three government environmental regulation mechanisms—environmental penalties, environmental subsidies, and environmental certification—on corporate green innovation. The regression coefficient for *Carbon_Policy* × *Govregul1* was 0.0321, significant at the 1% level; for *Carbon_Policy* × *Govregul2*, the regression coefficient was 0.0213, but the result is not significant; for *Carbon_Policy* × *Govregul3*, the regression coefficient was 0.0447, passing the significance test at the 5% level. This indicates that low-carbon city policies promote corporate green innovation through environmental penalties and environmental certification mechanisms of government environmental regulation, whereas the environmental subsidy mechanism does not have a significant effect on enhancing corporate green innovation.

7.3. Corporate Environmental Information Disclosure

Corporate environmental information disclosure is crucial for corporate green innovation. Based on the intensity of environmental information disclosure, listed companies disclose environmental information in three ways: (1) within the company's annual report; (2) within the corporate social responsibility (CSR) report; or (3) through a separate environmental report. Accordingly, this study analyzed the impact of these three mechanisms of corporate environmental information disclosure—company annual reports (*Envinfor1*), CSR reports (*Envinfor2*), and separate environmental reports (*Envinfor3*)—on corporate green innovation. The specific regression results for these mechanisms are presented in Table 13.

Table 13. Estimates of Corporate environmental information disclosure.

Variables	**(1)** **Annual Report**	**(2)** **CSR Report**	**(3)** **Environmental Report**
Carbon_Policy × *Envinfor1*	0.0221		
	(1.3557)		
Carbon_Policy × *Envinfor2*		0.1541 ***	
		(6.9130)	
Carbon_Policy × *Envinfor3*			0.3869 ***
			(4.8663)
Carbon_Policy	0.0447 *	0.0177	0.0571 ***
	(1.9143)	(0.8633)	(2.8473)
TobinQ	0.0042 ***	0.0041 ***	0.0041 ***
	(3.1476)	(3.1159)	(3.1456)
Mshare	−0.0317 ***	−0.0343 ***	−0.0320 ***
	(−2.7743)	(−2.9713)	(−2.7933)
ROE	0.0095	0.0103	0.0090
	(0.6967)	(0.7308)	(0.6573)
ATO	−0.0417 ***	−0.0413 ***	−0.0423 ***
	(−2.5858)	(−2.5829)	(−2.6236)
Size	0.3210 ***	0.3137 ***	0.3211 ***
	(25.4338)	(24.8325)	(25.4540)
Lev	0.0313	0.0504	0.0342
	(0.6940)	(1.1195)	(0.7584)
Board	0.0283	0.0327	0.0291
	(0.6848)	(0.7915)	(0.7051)
envregul	0.0085	0.0122	0.0088
	(0.8790)	(1.2591)	(0.9067)
Constant	−6.3831 ***	−6.2733 ***	−6.3887 ***
	(−21.2880)	(−20.9558)	(−21.3408)
City FE	YES	YES	YES
Year FE	YES	YES	YES
Firm FE	YES	YES	YES
Observations	26,425	26,425	26,425
R-squared	0.7489	0.7495	0.7492

Notes: ***, * represent regression coefficients that pass the test of significance at the 1%, 10% levels, respectively. Values in () are t-statistics.

Column (1) of Table 13 presents the regression estimation results for the corporate environmental information disclosure mechanism based on company annual reports, where the coefficient for *Carbon_Policy* × *Envinfor1* is 0.0221, which is not significant. Column (2) displays the regression results for the mechanism based on CSR reports, with the coefficient for *Carbon_Policy* × *Envinfor2* being 0.1541, which passes the significance test at the 1% level. Column (3) shows the regression results for the mechanism based on separate environmental reports, where the coefficient for *Carbon_Policy* × *Envinfor3* is 0.3869, also significant at the 1% level. This indicates that the LCUPs promote corporate green innovation through the environmental information disclosure mechanisms of CSR reports and separate environmental reports, while the mechanism based on company annual reports does not have a significant effect on enhancing corporate green innovation.

8. Conclusions and Policy Implications

Based on theoretical analysis, this paper takes listed companies in 234 prefecture-level cities in China from 2005 to 2020 as the research objects. Using a multi-temporal double-difference model, the empirical analysis of the effect of the construction of the LCUP on the enhancement of levels of green innovation in corporations was carried out. It was found that the establishment of LCUP has been conducive to the enhancement of the green innovation level in corporations. The positive effect has both city heterogeneity and corporate heterogeneity, which is manifested in the fact that the enhancement effect on the green innovation of corporations in cities of the Central and Eastern regions has been significantly stronger than in Western regions. The enhancement effect on the green innovation of corporations in cities with high levels of green finance is significantly stronger than that in cities with low levels of green finance, the enhancement effect on the green innovation of non-state corporate enterprises is significantly stronger than in state-owned operations, the enhancement effect on the green innovation of highly media-focused firms is significantly stronger than that in companies with low media attention, and the enhancement effect on the green innovation of highly digitized businesses is significantly stronger than that of low-digitization corporations. In addition, the results of the mechanism testing indicate that the enhancement of public environmental awareness, the strengthening of government environmental regulations, and the intensification of corporate environmental information disclosure are effective mechanisms of action for the establishment of LUCP to enhance the levels of green innovation in corporations. The above conclusions still hold after various robustness tests, such as the parallel trend test, placebo test, propensity-score-matching–double-difference method test, winsorization treatment, replacement of explanatory variables, and supplementation of missing variables.

These findings not only enhance our understanding of how low-carbon city pilot policies impact enterprises' green innovation, but also offer empirical references and evidence to support the formulation and optimization of policies in low-carbon cities.

Firstly, it is important to summarize the experiences gained from pilot policies, while continuing implementing and further optimizing the LCUP. On the one hand, the government needs to develop a comprehensive evaluation indicator system, including economic benefits, environmental benefits, social benefits, and other aspects, and to conduct systematic assessments of the effects of low-carbon city policies to provide a scientific basis for policy optimization. On the other hand, the government should also summarize the successes and lessons learned from the pilot policies to better understand the challenges and difficulties encountered during policy implementation. Based on these experiences, new pilot cities should be selected, considering different geographical locations and stages of development, to further validate and expand the pilot scope.

Secondly, it is crucial to develop targeted policy guidance plans according to different real-world scenarios. Based on our findings, it can be deduced that it is vital to boost innovation in non-state-owned enterprises through market incentives, utilize market mechanisms for green innovation, enhance regional green finance, support green financial institutions, and improve green finance information systems. Moreover, it is crucial to acknowledge the role of media oversight in promoting corporate transparency and encouraging responsible reporting on environmental issues. Enterprises should align more closely with societal expectations and take greater responsibility for economic, environmental, and social concerns. Additionally, recognizing the importance of digitalization and pushing for digital transformation to improve resource optimization, efficiency, and environmental monitoring is essential.

Lastly, it is essential to focus on the combination of policy tools, fully leveraging the channel effects of various policy instruments in policy implementation. The mechanism test results for low-carbon city policies indicate that enhancing public environmental awareness, strengthening government environmental regulation, and improving corporate environmental information disclosure are the three main channels through which these policies affect corporate green innovation. To elevate environmental awareness, it is crucial to conduct environmental education and widespread environmental campaigns to raise public awareness of environmental issues. The government should utilize media and social platforms to disseminate knowledge and reiterate the importance of environmental protection, fostering a positive attitude towards green innovation. Additionally, encouraging public participation in environmental volunteer activities and lectures can enhance engagement and create an atmosphere of broader environmental conservation. Of course, from the perspective of strengthening government environmental regulation, establishing a comprehensive regulatory framework and improving environmental regulations are essential to ensure thorough and effective oversight of corporate environmental practices. Increasing penalties for environmental violations will elevate compliance costs, encouraging businesses to adhere to environmental laws and stimulate green innovation. Integrating advanced monitoring technologies like remote sensing and big data analysis can enhance the precision and timeliness of environmental behavioral monitoring. In addition, to enhance transparency, it is necessary to improve corporate environmental information disclosure, instituting mandatory disclosure regulations for environmental information including emissions data and environmental management measures. Establishing environmental incentive mechanisms, such as tax benefits and government rewards for enterprises that voluntarily disclose environmental information and implement effective environmental management, can motivate more proactive green innovation. Lastly, providing training and guidance on environmental information disclosure can help businesses better understand disclosure requirements and improve the quality and comparability of disclosed information.

This study explores the impact of low-carbon pilot city policies on enterprises' green innovation, enhancing the assessment of such policies and offering empirical evidence of their influence on enterprise innovation. Future research could focus on expanding indicators to measure green innovation in terms of both quantity and quality, for more precise metrics. Additionally, broadening the sample scope beyond urban areas in China to include other developing and developed countries would help validate the findings. Moreover, refining the selection criteria for universities and colleges, as well as enterprises with different orientations such as industry categories and R&D levels, could lead to more specific research outcomes.

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