

Original Research

Retesting the Innovation Motivation Effect of the Low-Carbon City Pilot Policy in China: Evidence from Supply Chains

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Abstract

Accurately evaluating the innovation motivation effect of the low-carbon city pilot policy is significant for improving and promoting the pilot policy. However, no study has specifically examined the above effect from the point of view of policy spillover effects among customers and suppliers. Based on this, we introduce the perspective of the supply chain spillover effect and collect annual data from Chinese-listed firms between 2008 and 2020. Using the differences-in-differences (DID) model, we have tested the relationship between the low-carbon city pilot policy in the location of the largest customer and affiliated suppliers' innovation behavior. Our findings indicate that implementing the low-carbon city pilot policy in the location of the largest customer incentivizes suppliers to invest in innovation. Additionally, our research finds that financing constraints and market monopoly power moderate the supply chain innovation spillover. Interestingly, the impact of the policy is more pronounced among suppliers in high-carbon and low-tech sectors as well as those in the eastern region.

Keywords: low-carbon city pilot policy, innovation motivation effect, China, supply chain spillover effect

Introduction

The Chinese economy has achieved remarkable progress, yet it also faces challenges of high energy consumption and environmental pollution. As a responsible nation, China has pledged to accelerate establishing a green, low-carbon, and circular economic system to reach the carbon peak by 2030 and carbon neutrality by 2060. Recognizing the crucial role of cities in promoting low-carbon development, the National Development and Reform

Commission initiated low-carbon city pilot programs in 2010. Since then, the pilot cities have steadfastly advanced various low-carbon initiatives, yielding promising results. Subsequently, the scope of the low-carbon pilot was gradually broadened in 2012 and 2017. As a comprehensive policy measure, the low-carbon city pilot policy features weak constraints, industry specificity, and policy integration [1]. It constitutes a critical component of the Chinese environmental policy system and provides a valuable attempt to explore the pioneering path of the low-carbon economy with distinctive Chinese characteristics. Therefore, practical evaluation of the pilot programs can provide supplementary evidence for China's green transformation.

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Early studies primarily focused on the impact of low-carbon city pilot policies on pollution control [2] and consumption reduction [3]. Later, researchers gradually explored their economic effects from various perspectives. The results suggest that low-carbon city pilot policies benefit regional economic development [4] and improve urban residents' lifestyles [5]. They also highlight these policies' significant role in promoting firms' development. As the core participants in city construction, firms are the primary source of energy consumption, pollutant emissions, and development transformation. Relevant studies suggest that implementing low-carbon city pilot policies can effectively enhance the total factor productivity of local firms [6] and promote high-quality development [7]. However, we must also consider the potential negative impact of these policies on the performance of high-polluting firms [8] and address the challenges stemming from balancing emission reduction and efficiency improvement.

Moreover, innovation incentives are the fundamental goal for the government to implement environmental policy, which is crucial for reducing emissions and building low-carbon competitiveness. Therefore, exploring the impact of environmental policy on firms' innovation behavior has always been essential for studying the effects of environmental policy. Based on the Porter Hypothesis, previous studies on the relationship between environmental policy and firms' innovative behavior focused on verifying innovation compensation and cost effects [9, 10]. As for the low-carbon city pilot policy, scholars generally believe it can improve local firms' technological innovation [1, 7, 11-13], resulting in an innovation compensation effect. Furthermore, considering that one of the core objectives of the low-carbon city pilot is the accumulation and promotion of low-carbon development experience, the policy itself has specific demonstration and spillover effects. Therefore, in addition to studying the impact of pilot policy on local firms, it is necessary to explore the policy spillover effects, especially whether the pilot policy can generate innovation incentive effects on firms in other areas. For example, Tian and Liu [12] investigated the effect of the low-carbon city pilot policy on the green innovation activities of firms in companion cities, providing supplementary evidence for exploring the innovation incentive effect. The supply chain connection formed by direct interest relations and business exchanges is another essential channel for policy spillover, as it is more likely to trigger the social multiplier effect [14]. Additionally, resource acquisition and external support during the firm's innovation are closely linked to cooperative firms in the supply chain [15]. Therefore, exploring the innovation spillover effect of the low-carbon city pilot policy based on the supply chain spillover effect perspective is needed to provide more evidence for testing the pilot policy's innovation compensation effect.

The spillover effect refers to the impact of an organization's activity on individuals and organizations

outside the organization [12]. Regarding the supply chain spillover effect, based on the cooperation between upstream and downstream firms, scholars have studied the categories of multi-level supply chain spillover effects, such as the information spillover effect. Earlier studies confirmed the effects of customers' monthly sales announcements on the supplier's stock price fluctuations [16]. Subsequently, studies confirmed that customers' earnings announcement information [17] and risk information [18] could impact suppliers' behavior. In the knowledge spillover effect, Javorcik [19] found a significant knowledge spillover between customers and suppliers from different countries. Isaksson and Seifert [20] confirmed that this spillover effect is more apparent at the initial cooperation stage. Another example is the policy spillover effect. Chen and Liu [14] confirmed that establishing a national high-tech zone in the location of the largest customer could improve the sales revenue of affiliated suppliers. Yu et al. [15] built a theoretical model based on production network theory and verified the innovation spillover of the carbon emission trading pilot policy. The discussion on the spillover effect of policy content on the supply chain offers a new perspective for investigating the implementation effect of macro policies. It also provides an essential theoretical basis for this paper to explore the supply chain spillover effect of low-carbon city pilot policies.

In summary, to confirm the motivating impact of the low-carbon city pilot policy on innovation while considering possible supply chain spillover effects, this study will first investigate the influence of the pilot policy in the location of the largest customer on affiliated suppliers' innovation investment. Two indicators related to firms' innovative behavior - external financing constraints and market monopoly power - will be examined as moderating factors in the policy spillover effect. Additionally, the cross-sectional analysis will be conducted based on the proportion of carbon emissions, technology content, and differences in local economic development. Based on these factors, the study concludes that implementing the low-carbon city pilot policy in the location of the largest customer encourages suppliers to invest in innovation.

The contributions of this study are threefold: Firstly, this study effectively pushes the study boundaries of the low-carbon city pilot policy's innovation motivation effect. Unlike the studies exploring the impact of low-carbon city pilot policies on local firms' innovation behavior and the effect of low-carbon city pilot policies on the green innovation activities of firms in neighboring cities, this article is based on the perspective of the supply chain spillover effect, providing more robust evidence of the incentive effect of the low-carbon city pilot policy. Secondly, the research on the policy spillover phenomenon between suppliers and buyers has not been sufficiently explored. No study has specifically examined the low-carbon city pilot policy as a target for supply chain spillover effects. This study confirms the beneficial dissemination of the low-carbon city

pilot policy in supply chain transmission channels. Finally, the impact of financing constraints and market monopolies on firms' innovative behavior has always been essential. However, research has yet to explore it from the perspective of supply chain spillovers. The results of this study indicate that financing constraints and market monopolies of suppliers can also regulate the impact of low-carbon policies in customers' locations on suppliers' innovative behavior.

This article proceeds as follows: Section 2 reviews the relevant literature and develops our hypothesis. Section 3 discusses the research design. Section 4 presents the empirical results. Section 5 finishes the robustness test. Section 6 is the cross-sectional analysis. Section 7 presents the conclusions and recommendations of the study.

Relevant Literature and Hypothesis Development

The Low-Carbon City Pilot Policy

The low-carbon city pilot policy intends to attain a balance that benefits both emission reduction and economic development. Research on the low-carbon city pilot policy can be traced back to the initial theoretical discussion on the meaning and attributes of low-carbon cities [21, 22] and the policy design concerning implementation logic and construction path [23, 24]. As the scope of the pilot broadened, the policy's effects began to emerge. Numerous studies have examined the net effect of the low-carbon city pilot policy on pollution control [2, 3] and microfirms, predominantly focusing on the relationship between the policy and firms' development.

Most studies have confirmed the positive impact of the low-carbon city pilot policy on firms' development. Concerning production efficiency, the policy aids firms in improving their technological innovation by reducing external financing constraints [6], eventually leading to high-quality development [7]. Regarding social responsibility, Wang et al. [13] discovered that the low-carbon city pilot policy considerably boosts firms' environmental performance by enhancing the level of green innovation and environmental investment. Regarding firms' technology path selection, Hu and Yu [25] posit that the low-carbon city pilot has a guiding impact on the technology path transformation of manufacturing firms. Regarding innovation investment, most studies believe that the low-carbon city pilot policy encourages innovation [1, 6, 11-13], significantly impacting the innovation investment behavior of firms in peer cities [12].

The Relationship between Customers and Suppliers' Innovation Investment

Innovation investment is a critical strategic decision for firms to remain competitive [26]. Additionally,

suppliers are motivated to establish and maintain cooperative relationships by increasing relational investment, including innovative investment [27]. Therefore, analyzing customers' business status can provide valuable insights into suppliers' investment decisions. From an asset-specificity perspective, Sun and Zheng [28] confirmed that improving key customers' technical standards could encourage suppliers to improve their production technology. In line with the theory of Geographic Economics, Cheng et al. [29] believed that large customers' geographic proximity would strengthen their negotiation advantages and allow them to obtain more private information about suppliers, potentially resulting in the loss of suppliers' innovation benefits. According to the theory of resource dependence and signal transmission, An et al. [30] posited that positive earnings disclosures from customers could encourage suppliers to invest in innovation. Based on the production network theory, Yu et al. [15] have verified the innovation spillover effect of the carbon emission trading pilot policy, and the policy has a heterogeneous impact on the innovation behavior of upstream and downstream firms.

Based on the abovementioned analysis, scholars have examined the impact of the low-carbon city pilot policy on firms' behaviors through theoretical discussions and empirical analyses. As for innovation behavior, scholars have explored the relationship between the low-carbon city pilot policy and the innovation behavior of local firms. They also confirmed the horizontal innovation spillover from the pilot implementation in adjacent regions. However, they have not considered the potential vertical innovation spillovers during supply chain cooperation. Additionally, scholars have affirmed the impact of customer behavior on supplier innovation decisions from different perspectives. While some scholars have examined the relationship between the policy in the customer city and the supplier innovation decision, there has been no research testing whether the innovation behavior of suppliers is affected when implementing low-carbon city pilot policies in customer locations. Consequently, this study aims to adopt the supply chain perspective to investigate whether implementing the low-carbon cities pilot policy in the location of customers influences affiliated suppliers' innovation.

Hypotheses Development

The Low-Carbon City Pilot Policy in the Location of the Largest Customer and the Supplier's Innovation Investment

Innovative activities exhibit distinctive characteristics such as prolonged investment cycles, high risks, and significant uncertainty. As a critical strategic decision, in addition to being influenced by direct incentive mechanisms, affiliated firms' conduct (including those within the industry [12] and partners

[15, 27-29]) closely relates to firms' innovative decisions. Among them, being the primary customer with the highest purchase amount, the largest customer accounts for a relatively large proportion of the supplier's total sales and plays a crucial role in the supplier's survival and development. The demand content and transformation of the largest customers can specifically impact the suppliers' investment decisions. It is also crucial for the direction of the supplier's innovation investment and the value conversion of its innovation achievements. Therefore, this study will examine if the low-carbon city pilot policy implemented in the largest customer city can affect affiliated suppliers' innovative investment.

On the one hand, the imbalanced exchange of goods, capital, and interests between customers and suppliers pressures the latter to increase their investment in eco-friendly innovation to comply with the evolving requirements of the former [31]. Specifically, when the low-carbon city pilot policy is implemented in the largest customer city, local firms' emission and carbon reduction measures are closely linked to their production processes [32]. These measures include adjusting the proportion of production elements and updating the disposal technology for environmental pollutants [33, 34]. This, in turn, sets forth new supply requirements for upstream suppliers about green production transformation. With high uncertainty and conversion costs due to customer transformation, suppliers tend to increase innovative investment to improve traditional production processes, management modes, and product schemes. This approach simultaneously meets the cleaning needs of the largest customer while enhancing compatibility and collaboration between suppliers and customers' low-carbon transformation needs. This also avoids the costs and risks associated with the core customer transformation [18].

On the other hand, the low-carbon city pilot policy is a significant exploration that demonstrates the Chinese government's determination and confidence in green development. Since the launch of the first batch of low-carbon city pilot work in 2010, the pilot implementation scope has continuously expanded in 2012 and 2017. Following the launch of the low-carbon city pilot policy in the location of the first-largest customer, suppliers who exhibit a high degree of policy sensitivity and advanced green development awareness can take this opportunity to carry out innovative green activities. Implementing preventative environmental measures early on will allow suppliers to maintain a strong position in a future competitive market and gain an advantageous head start [35]. This will help suppliers compete effectively for government grants such as tax relief and financial subsidies and alleviate regulatory costs in the transformation process [1], ultimately leading to a successful low-carbon transformation. Based on this analysis, it is proposed that:

Hypothesis H1: The low-carbon city pilot policy in the location of the first largest customer positively incentivizes the supplier's innovation.

Moderating Role of Financing Constraints and Monopoly Forces

Investment in innovation requires substantial financial support and is characterized by high risk, long investment cycles, and unpredictability. Moreover, innovation activities are often tied to firms' core interests, making it impossible to fully disclose specific project details and exacerbating the information asymmetry between firms and investors. Asymmetric information is crucial to firms' external financing constraints [36]. Consequently, external financing constraints significantly impact firms' ability to carry out innovative activities [30]. Thus, this study examines the potential impact of differences in external financing constraints among suppliers on the spillover relationship. In light of this, we propose the following assumptions:

Hypothesis H2: The supplier's financing constraints can inhibit the promotion of the low-carbon city pilot policy in the first largest customer city on the supplier's innovation investment.

Schumpeter's innovation theory shows a positive correlation between market monopoly power and the firm's innovation activities [37]. Market competition may reduce a monopoly's profits and hinder funding for innovation. However, monopolies often maintain their leading edge through innovative breakthroughs, and this edge increases their likelihood of success in innovation endeavors. Nonetheless, some scholars argue that monopolies do not significantly promote innovation and that competitive markets are more conducive to technological advancements [38, 39]. Recent studies suggest that the pilot policy of low-carbon cities can intensify industrial competition [8]. Thus, this paper examines the potential impact of the market monopoly power of suppliers on the spillover effect and presents competitive assumptions.

Hypothesis H3a: The supplier's market monopoly power can aggravate the promotion of the low-carbon city pilot policy in the first largest customer city by the supplier's innovation behavior.

Hypothesis H3b: The supplier's market monopoly power can inhibit the promotion of the low-carbon city pilot policy in the first largest customer city based on the supplier's innovation behavior.

Research Design

Data Sources and Sample Selection

We have selected the A-share listed firms on the Shanghai Stock Exchange and Shenzhen Stock Exchange from 2008 to 2020 as our sample group. Our selection process includes the following steps: Initially,

we obtained the supplier's sales table based on the CSMAR database and identified the top five customers. Subsequently, we selected the customer with the highest purchase amount as our sample. We excluded samples that did not disclose the customer's name, such as Legal Person One and Customer 1. Furthermore, we eliminated individuals, institutions, government agencies, financial customers, and firms labeled as ST and * ST during the study period. To ensure that the implementation of the pilot policy in the customer city influenced changes in supplier R&D investment, we have removed the observation that suppliers have already been established as low-carbon pilot cities before the cooperative customer cities are set up as pilot cities in order to avoid disruptions to the supply chain spillover effects caused by the pilot policy in the supplier location [14]. Finally, we obtained 4379 valid samples. The variables used in this study and financial data related to the firms were sourced from the CSMAR database.

Research Model

Benchmark Model

This study investigates the impact of implementing the low-carbon city pilot policy in the largest customer city on the supplier's innovation. Considering the effective application of the DID model in evaluating the implementation effect of economic policy [40, 41], this study also employs an asymptotic DID mode:

$$R\&D_{i,t} = \beta_0 + \beta_1 \text{treat} - \text{period}_{k,t} + \rho X'_{i,t} + \mu_{j,t} + \delta_{r,t} + \alpha_i + \gamma_t + \varepsilon_{i,j,r,t} \quad (1)$$

Among them, $R\&D_{i,t}$ is the innovation investment level of the supplier i in the year of t , $\text{treat} - \text{period}_{k,t}$ represents the intersection term of dummy variables $\text{Treat}_k + \text{Period}_{k,t}$, and β_1 is the core coefficient in this study. Here, if β_1 is significantly positive, it indicates that implementing the low-carbon city pilot policy in the largest customer city can effectively promote the supplier's innovative investment. In addition, $X'_{i,t}$ is the set of control variables, α_i is the individual fixed effect, γ_t is the time fixed effect, $\mu_{j,t}$ and $\delta_{r,t}$ respectively representing the fixed effect of industry and province over time, $\varepsilon_{i,j,r,t}$ is the random interference term.

Moderating Effect Test

To verify the moderating effects of the supplier's financing constraints and market monopoly power, we set the moderating effect models as follows:

$$R\&D_{i,t} = \partial_0 + \partial_1 \text{treat} - \text{period}_{k,t} + \partial_2 \text{treat} - \text{period} * KZ + \partial_3 KZ + \rho X'_{i,t} + \mu_{j,t} + \delta_{r,t} + \alpha_i + \gamma_t + \varepsilon_{i,j,r,t} \quad (2)$$

$$R\&D_{i,t} = \varphi_0 + \varphi_1 \text{treat} - \text{period}_{k,t} + \varphi_2 \text{treat} - \text{period} * \text{Competitor} + \varphi_3 \text{Competitor} + \rho X'_{i,t} + \mu_{j,t} + \delta_{r,t} + \alpha_i + \gamma_t + \varepsilon_{i,j,r,t} \quad (3)$$

Where the moderating variables KZ and Competitor are used to measure the supplier's external financing constraints and the market monopoly power, respectively. Given a significant positive correlation between $R\&D$ and $\text{treat} - \text{period}$, if KZ presents a significant negative moderation effect, the interaction coefficient ∂_2 will be negative and significant. Meanwhile, if φ_2 is significant and positive, it will indicate that the supplier's market monopoly power has a positive moderation effect on the relationship between the low-carbon city pilot policy in the first largest customer city and the supplier's innovation investment.

Variable Definition

The Supplier's Innovation Investment

We assess the investment level of suppliers' innovative activities by calculating the proportion of gross expenditure on research and development as a percentage of operating revenue [30, 42, 43].

The Intersection Term of Dummy Variables

We set the intersection term of the time dummy and the policy processing dummy $\text{Treat}_k + \text{Period}_{k,t}$ as the explanatory variable ($\text{treat} - \text{period}$). Suppose the location of the supplier's largest customer is set as the low-carbon pilot, the value of the item Treat_k and the year $\text{Period}_{k,t}$ when the policy occurs and the years after it are set to 1, and other items are set to 0.

Moderator Variable

Financing constraints (KZ). We measure the supplier's external financing constraints by calculating the KZ index [44]; a higher value means the firm faces a higher financing constraint in a determined time.

Monopoly power (Competitor). We use the Lerner index [45] to measure the supplier's market monopoly power, and a higher value means a higher monopoly position in the market.

Overall, all variable definitions are summarized in Table 1.

Results and Discussion

Descriptive Statistics

Table 2 reports the descriptive statistics. The analysis shows that over the sampling period, the mean percentage of investment in innovation by suppliers stood at 0.0236, indicating that the perception of innovation amongst Chinese listed firms is deficient, with noticeable inter-firm disparities. Furthermore,

Table 1. Variable definitions.

Variable	Definitions
<i>R&D</i>	Suppliers' innovation investment level
<i>treat – period</i>	The intersection term of the time dummy and the policy processing dummy
<i>lnsize</i>	Firms' size
<i>lnage</i>	Firms' listing age
<i>lnTobinQ</i>	The price ratio of a firm's market value to its asset reset
<i>lndebts</i>	Logarithm of asset liability ratio
<i>ROE</i>	Return on equity of firms
<i>Top1</i>	The ratio of the shares of the listed firms held by the largest shareholder to the total share capital of the firms
<i>Independent</i>	Natural logarithm of the total number of the firm's board of directors
<i>Duality</i>	Are the General Manager and Chairman integrated or not?
<i>KZ</i>	External financing constraints
<i>Competitor</i>	Market monopoly power

Table 2. Descriptive statistics of main variables.

Variable	Obs	.Mean	Std	Min	Max
<i>R&D</i>	4379	0.0236	0.0497	0	1.2591
<i>lnsize</i>	4379	21.7530	1.3307	0	26.8397
<i>lnage</i>	4379	1.9813	0.9407	0	3.4012
<i>lnTobinQ</i>	4379	0.6015	0.5449	-0.3802	6.5925
<i>lndebts</i>	4379	-0.9789	0.7173	-4.9505	3.4489
<i>ROE</i>	4379	0.0208	0.4841	-30.9587	2.8101
<i>Top1</i>	4379	0.1434	0.1231	0.0015	0.8097
<i>Independent</i>	4379	0.3659	0.0545	0	0.7143
<i>Duality</i>	4379	0.2217	0.4154	0	1

we refrain from reiterating the explanation of other control variables here.

Primary Analysis

Based on Equation (1), this study first investigates the impact of the low-carbon city pilot policy in the first largest customer city on the supplier's innovative investment. The final test results are presented in Table 3, which includes column (1), showing the regression results without controlling for any variables, and column (2), including control variables. Columns (1) and (2) also simultaneously control fixed effects at individual, time, and city levels, while column (3) further controls for industry-level fixed effects. Additionally, all regression results in this study employ cluster standard errors at the city level. Table 3 reveals that implementing the low-carbon city pilot policy in the largest customer city positively impacts suppliers' innovative investment. Specifically, the

coefficient for *treat – period* in column (1) is significant at a 5% level, at 0.1204. When control variables are included in column (2), the coefficient for *treat – period* remains significantly positive at 5%, with a slight increase. In column (3), the coefficient rises to 0.1655, indicating factors that affect innovation among firms at the industry level. Therefore, we can confirm that implementing the low-carbon city pilot policy in the largest customer city promotes innovation investment for affiliated suppliers, and thus, our hypothesis H1 is verified.

Next, regarding previous studies [46], this paper uses the generalized PSM-DID to alleviate the potential selection bias. Specifically, we use the control variables as matching covariates, and the propensity scores corresponding to each sample are calculated using the Logit model. Then, k-nearest neighbor, caliper, and kernel matching methods are used to match the samples of low-carbon pilot cities with the control group. The value of k in k-nearest neighbor matching

Table 3. The low-carbon city pilot policy in the location of the largest customer and the supplier's innovation.

	(1)	(2)	(3)	(4)	(5)	(6)
	<i>R&D</i>	<i>R&D</i>	<i>R&D</i>	<i>R&D</i>	<i>R&D</i>	<i>R&D</i>
<i>treat – period</i>	0.1204**	0.1387**	0.1665**	0.1661**	0.1662**	0.1664**
	(0.0605)	(0.0580)	(0.0737)	(0.0737)	(0.0737)	(0.0737)
<i>lnsize</i>		0.1836***	0.1199	0.1197	0.1190	0.1211
		(0.0569)	(0.0832)	(0.0833)	(0.0832)	(0.0836)
<i>lnage</i>		0.0045	-0.0649	-0.0613	-0.0635	-0.0638
		(0.0643)	(0.0822)	(0.0816)	(0.0825)	(0.0825)
<i>lnTobinQ</i>		0.0902	0.0625	0.0626	0.0613	0.0655
		(0.0656)	(0.0957)	(0.0962)	(0.0956)	(0.0966)
<i>Indebts</i>		-0.0133	-0.0578	-0.0573	-0.0580	-0.0587
		(0.0351)	(0.0792)	(0.0792)	(0.0793)	(0.0798)
<i>ROA</i>		-0.0475***	-0.1846	-0.1847	-0.1857	-0.1853
		(0.0127)	(0.1142)	(0.1143)	(0.1141)	(0.1148)
<i>Top1</i>		0.1311	-0.5380	-0.5372	-0.5384	-0.5412
		(0.3213)	(0.4488)	(0.4482)	(0.4486)	(0.4489)
<i>Independent</i>		-0.4489	-0.5504	-0.5599	-0.5606	-0.5499
		(0.5290)	(0.5499)	(0.5523)	(0.5522)	(0.5501)
<i>Duality</i>		0.1828***	0.1731**	0.1734**	0.1728**	0.1738**
		(0.0647)	(0.0692)	(0.0693)	(0.0692)	(0.0693)
<i>_cone</i>	0.7670***	-3.2008**	-1.5689	-1.5704	-1.5484	-1.6005
	(0.0111)	(1.2769)	(1.7690)	(1.7706)	(1.7686)	(1.7790)
<i>Individual/Time/ City</i>	YES	YES	YES	YES	YES	YES
<i>Industry</i>	NO	NO	YES	YES	YES	YES
<i>N</i>	4379	4379	4379	3917	4145	4344
<i>adj.R²</i>	0.4390	0.4410	0.2160	0.2100	0.2110	0.2130

Standard errors in parentheses: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

is 4, and the radius of caliper matching is 0.01. We match the treatment group year by year, and after matching, there is no significant difference in the mean values between the treatment group and the control group samples. The regression results of the k-nearest neighbor matching method, caliper matching method, and kernel matching method are reported in columns (4) to (6) in Table 3. The results show that the estimation results using different matching methods are consistent with the benchmark regression results, further verifying the robustness of the core conclusion in this paper.

The Moderating Effect

1. Financing constraints. The moderated regression results are presented in columns (1) and (2) of Table 4.

It is evident that, under different control effects, the coefficients for *treat – period KZ* are -0.0227 and -0.0222, respectively, which are statistically significant at the 10% level. Thus, hypothesis H2 is supported as the negative impact of external financing constraints on firms' innovation behavior in the supply chain spillover effect is confirmed.

2. Monopoly power. The moderated results are displayed in columns (3) and (4) of Table 4. The coefficients for *treat – period* are 0.2597 and 0.2375, respectively, and are statistically significant at the 5% and 10% levels. These results indicate that suppliers' monopoly power can positively moderate the promotion effect of the pilot policy of low-carbon cities in the first largest customer city on their innovation behavior. Therefore, hypothesis H3a is confirmed.

Table 4. Moderating Effect: external financing constraints and market monopoly forces.

	(1)	(2)	(3)	(4)
	<i>R&D</i>	<i>R&D</i>	<i>R&D</i>	<i>R&D</i>
<i>treat – period</i>	0.0860*	0.0993**	0.1042*	0.1236**
	(0.0466)	(0.0472)	(0.0614)	(0.0600)
<i>treat – period + KZ</i>	-0.0227*	-0.0222*		
	(0.0128)	(0.0133)		
<i>KZ</i>	0.0054	0.0149		
	(0.0068)	(0.0091)		
<i>treat – period + Competitor</i>			0.2597**	0.2375*
			(0.1297)	(0.1273)
<i>Competitor</i>			-0.0140	-0.0328
			(0.0377)	(0.0460)
<i>Controls</i>	YES	YES	YES	YES
<i>_cons</i>	0.7701***	-0.5255	0.7677***	-3.1540**
	(0.0140)	(0.8372)	(0.0112)	(1.3136)
<i>Individual/Time/City</i>	YES	YES	YES	YES
<i>Industry</i>	NO	YES	NO	YES
<i>N</i>	4379	4379	4379	4379
adj. <i>R</i> ²	0.5335	0.5308	0.4382	0.4402

Robustness Test

Parallel Trend Test: Based on the Event Study Method

The DID model is established on the premise that the processing and control groups adhere to the parallel trend assumption, which states that the trend of suppliers' innovation investment behavior is parallel before implementing the pilot policy. This paper adopts the event study method to test this hypothesis, as seen in other studies [47]. The calculation formula is as follows, $Pre_{k,t}$ is the year t

before the low-carbon pilot city k is established as the pilot city, and $Post_{k,t}$ is the year after the city is established as the pilot city.

$$R\&D_{i,t} = \omega_0 + \sum_{t=1}^4 \gamma_{-t} Pre_{k,t} + \sum_{t=1}^5 \gamma_t Post_{k,t} + \rho X'_{i,t} + \mu_{j,t} + \delta_{r,t} + \alpha_i + \gamma_t + \varepsilon_{i,j,r,t} \quad (4)$$

Fig. 1 reports the test results. We regard *current* as the base period. *Pre1-4* represents one to four years before the pilot policy, and *Post1-5* represents one to five years after. It can be seen from Fig. 1 that before the implementation of the low-carbon city pilot policy in the cities where the largest customers are located,

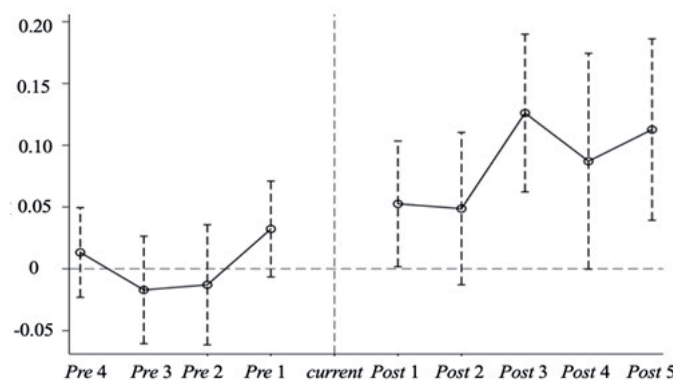


Fig. 1. Parallel Trend Test.

the coefficient for effect on suppliers' innovation investment was not statistically significant. However, after implementing the pilot policy, the coefficients are positive, and the first, third, fourth, and fifth periods are significant. So far, the sample data has passed the parallel trend test.

Placebo Test

We use the placebo test to conduct a robustness check to eliminate other factors. This study randomly generates a virtual low-carbon city test list, maintaining the same number of tests as the actual pilots. We reran the regression analysis based on Equation (1) and performed the placebo test five hundred times. The results shown in Fig. 2 indicate that the estimated coefficient values are concentrated around 0, which roughly follows the normal distribution, and the actual regression coefficient value of 0.1665 is not included in the results. Therefore, our conclusion is robust.

Cross-Sectional Analyses

Discussion Based on Carbon Emissions

Studies suggest the low-carbon city pilot policy primarily impacts firms in high-carbon sectors [6,48,49]. Similarly, based on the spillover effects through the supply chain, this study believes that low-carbon city pilot policies implemented in the largest customer cities will significantly affect suppliers' innovation investments in high-carbon emission groups. This study refers to the China Carbon Emission Trading Report (2017) to verify this hypothesis and classify the sample firms into high- and low-carbon emission groups. The results of the group tests presented in Table 5 Panel A indicate that the pilot policy's impact on suppliers' innovation investment is concentrated mainly in high-carbon emission groups. This is consistent with previous research [6, 48, 49], which suggests that firms operating in high-carbon sectors are the primary targets of environmental regulations.

Discussion Based on the Technological Content

The technological content of a firm often reflects its differences in factor intensity and its ability to respond to customers' low-carbon needs [50]. Using the Classification of High-Tech Industries (Manufacturing) (2013) published by the National Bureau of Statistics, we divided the suppliers into high-tech and low-tech groups and conducted group tests. As shown in Table 5, Panel B, the pilot policy in the largest customer city only promoted the innovation behavior of low-tech suppliers. One possible explanation is that sustaining a high level of R&D investment has become necessary for high-tech firms to maintain a competitive advantage. The transformation of customers' demand has not become the primary factor driving their R&D investment adjustments. Low-tech firms, on the other hand, typically have a weaker low-carbon foundation. In the face of customers' low-carbon needs, rapid and timely innovation adjustments can help them better meet their requirements and maintain their collaborative relationships.

Discussion Based on the Regional Economic Development Level

Considering significant regional economic development differences, we divided our sample of suppliers into eastern, central, and western groups based on the economic development level of their respective cities. As presented in Table 5, Panel C, the spillover effects of the low-carbon policy investigated in this study only significantly impact suppliers in the eastern region and have no significant effect on suppliers in the central and western regions. One possible explanation is that the green consciousness in the eastern region has always been higher than in other regions, and firms in this region have more experience with green development [51].

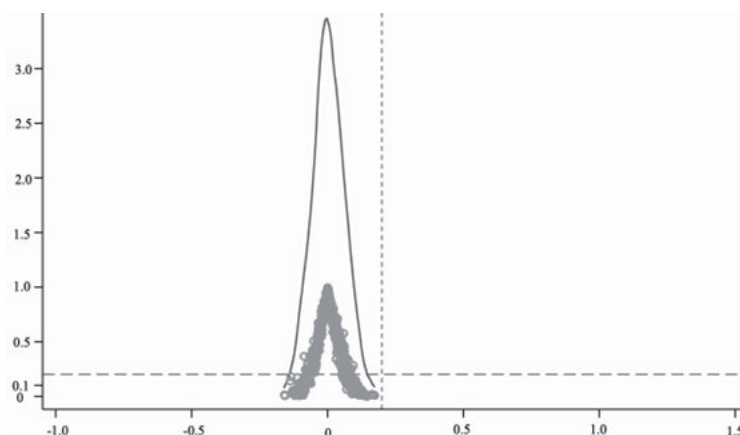


Fig. 2. Placebo test.

Table 5. Cross-sectional analysis results.

Panel A: Group by the carbon emission						
	High	High	Low	Low		
	<i>R&D</i>		<i>R&D</i>			
<i>treat – period</i>	0.2191**	0.2268**	0.0677	0.0246		
	(0.0893)	(0.0932)	(0.1044)	(0.1367)		
<i>Controls Individual/Time/City</i>	YES	YES	YES	YES		
<i>Industry</i>	NO	YES	NO	YES		
<i>N</i>	2510	2510	1869	1869		
adj. <i>R</i> ²	0.508	0.488	0.527	0.391		
Panel B: Group by the technological content						
	High-tech	High-tech	Low-tech	Low-tech		
	<i>R&D</i>		<i>R&D</i>			
<i>treat – period</i>	0.1579	0.1443	0.2387***	0.3648**		
	(0.1108)	(0.1084)	(0.0879)	(0.1516)		
<i>Controls/Individual/Time/City</i>	YES	YES	YES	YES		
<i>Industry</i>	NO	YES	NO	YES		
<i>N</i>	2590	2590	1789	1789		
adj. <i>R</i> ²	0.286	0.045	0.138	0.092		
Panel C: Group by the degree of economic development in the location of suppliers						
	Eastern	Eastern	Middle	Middle	West	West
	<i>R&D</i>		<i>R&D</i>		<i>R&D</i>	
<i>treat – period</i>	0.1422*	0.1828*	0.1061	-0.1176	0.1961	-0.7748
	(0.0844)	(0.1062)	(0.1298)	(0.1297)	(0.1224)	(0.5354)
<i>Controls/Individual/Time/City</i>	YES	YES	YES	YES	YES	YES
<i>Industry</i>	NO	YES	NO	YES	NO	YES
<i>N</i>	2389	2389	1160	1160	830	830
adj. <i>R</i> ²	0.578	0.535	0.420	0.257	0.400	0.707

Conclusions

This study presents the concept of the supply chain spillover effect as a means to analyze the relationship between low-carbon city pilot policies and the innovative behavior of firms. Our findings suggest that implementing low-carbon city pilot policies in the location of the largest customer can positively encourage affiliated suppliers to make innovative investments, even if the supplier's city has not implemented the pilot policy. This study provides strong evidence to verify the innovation motivation effect of low-carbon city pilot policies. Furthermore, this effect may be attenuated when suppliers face greater financing constraints. Additionally, suppliers with significant market monopoly power can intensify the innovation motivation effect of pilot policies. Low-carbon city

pilot policies in the largest customer's city have a more prominent impact on suppliers in high-carbon and low-tech sectors and suppliers in the eastern region.

The theoretical contributions of this paper are listed below.

First, it affirms the feasibility of stimulating cooperative suppliers to innovate by implementing the low-carbon city pilot policy in the largest customer city. The low-carbon city pilot policy is a significant strategy by the Chinese government to achieve low-carbon development. Its innovative stimulant effect could provide valuable reference points for designing other environmental policies in China. Unlike previous studies focusing on the impact of pilot policies on local firms' innovation behaviors, this research focuses on their spillover effects. Given the mutual interests of supply chain cooperatives, it highlights the link between

the low-carbon city pilot policy in the location of the largest customer and the cooperative supplier's innovative investments. This provides a unique perspective for understanding innovative incentives for low-carbon city pilot policies. Regarding the spillover effect of policy content on the supply chain, this paper also complements the approach of testing the implementation effects of macro policies.

Second, policy spillover effects between supply chain cooperative firms have garnered the interest of academics. Unlike other research examining the creation of national high-tech zones and the carbon emission trading pilot policy, this paper investigates the spillover effects of the low-carbon city pilot policy, a comprehensive policy. The results of this paper enhance the understanding of policy spillover relationships between suppliers and customers. The above discussion also provides theoretical support for establishing positive and orderly supply chain relationships.

Third, this study integrates two conventional factors related to firms' innovation behavior – financing constraints and market monopolistic forces. Specifically, the financing constraints of suppliers might obstruct the promotion of the low-carbon city pilot policy on supplier innovation investment in the customer city. This highlights the significance of financial support for business innovation behaviors. Moreover, the market monopoly of suppliers supports them in responding to customer demands and the trend of low-carbon development by escalating investment in innovation. Therefore, based on the perspective of supply chain spillover, this article supports the conclusions of traditional research and provides a theoretical supplement to theories about financing constraints and market monopolistic forces.

Based on the conclusions drawn in this study, we suggest several policy implications: Firstly, the government should prioritize the reinforcement and implementation of low-carbon city pilot policies. Compared to other policies and regulations with explicit objectives, low-carbon city pilot policies simultaneously emphasize macroeconomic regulation and independent innovation – a beneficial exploration by the Chinese government. This study has proved the influence of the pilot policy in the location of the largest customer on affiliated suppliers' innovation behavior. Such positive social effects underscore the reference value of this policy to environmental policy design in China. At the same time, the government should pay great attention to the financial constraints firms face during the green transformation, introducing effective incentives such as tax reductions and subsidies to reduce the burden and facilitate the ultimate low-carbon transition. Secondly, the government must pay attention to the impact of regulations on the primary target and the external spillovers that may emerge during the implementation process. This includes partners in production networks and businesses in the same industry. In this regard, policies should be formulated to ensure the effects are

holistic and comprehensive. Finally, policies at different levels should address the imbalance across regions and industries. This study confirms that implementing carbon-emission-reduction technologies in high-carbon sectors is essential to realizing low-carbon policies. It also highlights the significance of low-tech businesses in enabling the distribution of green development. Local governments should formulate targeted and specific guidance plans to address these differences across industries. As for regional development, the eastern region should be the reference for achieving low-carbon development compared to other regions.

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Conflict of Interest

The authors declare no conflict of interest.

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