Group Project Report

QF604 - Econometrics of Financial Markets

CAI YIHAN

LEE KAISHAN

PANG HANYU

YU CHUNXUE

Lee Kong Chian School Of Business

SINGAPORE MANAGEMENT UNIVERSITY

Singapore, Mar 2024

The impact of low-carbon city pilot policy on corporate green innovation: Evidence from China

CAI YIHAN, LEE KAISHAN, PANG HANYU, YU CHUNXUE

March 9, 2024

Abstract

Based on the patent application data of A-share listed companies from 2006 to 2019, the empirical analysis study shows that: LCCP policy has a positive incentive effect on enterprises' green patent applications; enterprises in the eastern region have an obvious promotion effect compared with enterprises in other regions; non-state-owned enterprises are more likely to be incentivized; and patent applications have a significant increase under the dual effects of academic experience and financial subsidies. The conclusion verifies that the LCCP policy promotes the research and development of green patents of listed companies, and at the same time gives important insights that can further promote the LCCP policy and promote the green technological innovation of enterprises.

Keywords: LCCP policy, green innovation, DID

1 Introduction

It has been widely substantiated that climate change could not only cause natural disasters but also affect corporate behaviors. The most notable one is that firms need to follow some environmental regulations and take social responsibility, serving for the goals of sustainable development. Subsequently, the term "green innovation", proposed by Rhodes and Wield (1994), is becoming a hot topic. This term refers to the process from research to marketization of environmental protection products and technologies. However, the benefits of green innovation are somewhat difficult to show in a short period of time. To encourage profit-driven firms to undertake environmental responsibility and engage in green innovation activities, governments tend to implement environmental regulations to facilitate corporate green transformation. However, there is lack of understanding on whether and how such policies promote corporate green innovation.

Based on the Porter hypothesis, prior studies found three relationships between the environmental regulation and corporate green innovation. Some studies revealed that environmental regulations may inhibit firms' green innovation (Gollop and Robert, 1983; Wagner, 2007; Milani, 2017), while some researchers found a positive association between the environmental regulation and green innovation (Brunnermeier and Cohen, 2003; Frondel et al., 2007; Hille et al., 2020). Furthermore, a nonlinear relationship has been observed between environmental regulations and corporate green innovation (Lanjouw and Mody, 1996; Scherer et al., 2000; Lanoieet al., 2008). The inconsistent evidence calls for future studies to examine the impact of environmental regulations on corporate green innovation in a specific setting to judge its effectiveness. This study focuses on the China's environmental regulation, namely the low-carbon city pilot (LCCP hereafter) policy adopted by the China's National Development and Reform Commission (NDRC) in 2010, due to its two unique characteristics. First, it is relatively flexible. Each pilot city has its own decision-making power. Local governments in these cities can formulate its own development plan according to the industrial structure, resources endowments, and technological advantages. Second, the LCCP policy is rather comprehensive because it is a combination of policy instruments including mandatory, voluntary, market-based, and humanism-oriented policies. According to the Porter hypothesis, appropriate environmental regulation can facilitate corporate green innovation (Porter and van der Linde, 1995). Therefore, we assume that the LCCP policy tailored to local conditions might promote corporate green innovation.

Prior studies have been dedicated to identifying the importance of the LCCP policy in reducing urban carbon emissions (Sinn, 2008; Lo, 2014; Song et al., 2020). However, these studies are generally silent about the impact of the LCCP policy on corporate green innovation. Therefore, we take up the research challenge with a special focus on whether and how the launch of LCCP policy shapes corporate green innovation activities.

Further, the question that how the LCCP policy affects corporate green innovation is still open. To well answer this question, it needs to come back to the two goals of the policy. The LCCP policy was issued to stimulate corporate innovation and reduce carbon emissions. Given its flexibility and potential, local governments may exert the "push and pull effect" of environmental policies on green innovation (Hojnik and Ruzzier, 2016). In this case, the effect is embodied in the compliance and regulation effects. First, based on the signal transmission theory, the LCCP policy stimulates the internal motivation of energy-hungry firms for green transformation so as to encourage them to develop green innovation. Specifically, local governments introduce serious policies to guide the green development and provide financial support and technical assistance for corporate green innovation. After receiving these green signals, stakeholders will stimulate firms to avail of the benefits of innovation through formal talks, inquiry letters and business cooperation, especially for those with low research and development (R&D) intensity. Therefore, firms with low R&D intensity are more willing to comply with the policy for sustainable development (Huang and Li, 2017). Second, the LCCP policy internalizes the externality of pollution by shaping the pressure of regulation and increasing pollution costs, forcing firms to adopt green innovation. For example, high-polluting firms will be shut down or fined for rectification by the local government, which will decrease business performance and hurt their public image. Consequently, the profit-seeking motivation would force firms, especially those with high environmental costs (EC), to engage in innovation for costing saving and reputation restoring. Through this mechanism, the goals of the LCCP policy might be achieved. To sum up, the compliance effect and the regulation effect are two different paths to the same destination – realizing corporate green innovation. They stimulate the innovation motivation of different firms (firms with low R&D intensity and firms with high EC) by means of encouragement and punishment, respectively.

Moreover, considering the fact that the LCCP policy involves a wide range of participants and areas, the policy effectiveness might be affected by both internal and external factors. Specifically, on the one hand, corporate executives with academic background would have higher moral feelings (Marquis and Tilcsik, 2013) and reputation expectations (Bowman, 2005). The fear of reputational damage from environmental fines or rectification drives them to actively promote green corporate transformation. On the other hand, government environmental subsidies could provide capital supplements to firms that lack innovation funds (Chen et al., 2022), and send positive signals to investors (Bai et al., 2018), promoting the compliance effect of the LCCP policy.

Based on the green patent application data of Chinese A-share listed firms in the Shanghai and Shenzhen stock markets from 2006 to 2019, we adopt a staggered difference-in-difference (DID) model to investigate the impact of the LCCP policy on corporate green innovation. Our results show that the LCCP policy can induce green innovation at the firm level by motivating firms with low R&D intensity and regulating firms with high EC. The effectiveness of the LCCP policy can be amplified when the firm has academic executives or receive government subsidies. Additionally, this positive impact is more pronounced for non-state-owned enterprises (non-SOE) and firms in the eastern region.

This study contributes to the literature in three aspects. First, previous studies examining the consequences of the LCCP policy merely focus on its effectiveness in emission reduction and regional heterogeneity, whereas our study investigates whether and how the LCCP policy affects firms' investment strategy, especially green innovation. We also find that the compliance effect and the regulation effect are potential mechanisms through which the LCCP policy facilitates corporate green innovation activities. Thus, our study enriches the quantitative and mechanistic analyses of the effect of LCCP policy on green innovation. Second, based on the implementation of the LCCP policy in China, we offer a new and specific foothold for the controversial Porter hypothesis. Choosing green invention patents as the complementary dependent variable further supports the hypothesis for sustainable development. Third, our findings have practical and policy implications.

We find the importance of internal and external factors on policy effectiveness, emphasizing the implications of executive characteristics and government subsidies for policymakers, practitioners, and academics.

For the first batch, the initial phase of LCCP policy was announced in 2010, included Guangdong, Liaoning, Hubei, Shaanxi, Yunnan, Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, Baoding, and more. Preliminary findings indicated a varied impact on green innovation, influencing corporate behavior and environmental responsibility.

The second batch extended the pilot policy to prominent cities like Beijing, Shanghai, Hainan, and others, emphasizing a nationwide commitment. Analysis spanning 2006 to 2019 revealed that LCCP-covered firms engaged more in green innovation activities compared to non-LCCP-covered firms. The policy particularly influenced low-innovation-intensive firms and compelled high-environmental-cost firms to shift towards green innovation.

The third batch continued the nationwide rollout, including cities such as Chengdu, Nanjing, Wuhan, and Lanzhou. Cities outlined specific goals, including establishing carbon management systems, exploring carbon trading mechanisms, and fostering green technology innovation.

2 Data and methodology

2.1 Sample Selection

In this paper, the patent application data of A-share listed companies from 2006 to 2019 are selected as the experimental samples, and for the sake of the accuracy and rigor of the samples, the data with the following conditions are screened out: 1) the financial industry, 2) those with less than two years of establishment, 3) those companies with serious missing key data, and 4) ST and *ST samples. The result is 27822.

Variable	N	Mean	SD	Min	Max
$Patent$	27,822	0.34288	0.76185	0	4.99721
$invpatent$	27,822	0.23149	0.61002	0	4.94876
$rPatent$	27,822	0.02985	0.10121	0	1
$rinvPatent$	27,822	0.0169	0.07295	0	1
$Policy$	27,822	0.46194	0.49856	0	1
$Acadbg$	27,822	0.46603	0.49885	0	1
Gsu	27,822	3.40591	5.93978	0	21.4875
age	27,822	1.97922	0.90311	0	3.4012
$size$	27,822	22.0235	1.29516	15.5773	28.3413
$debt$	27,822	0.4258	0.20619	0.00752	0.9976
$tobinQ$	27,822	1.03995	0.33031	0.521	5.56124
roa	27,822	0.04025	0.07558	-3.9944	0.59002
$capinten$	27,822	2.19359	1.43051	0.0876	8.99798
$independent$	27,822	0.37185	0.05486	0	0.8

Table 1： Descriptive statistics of main variables

The above data are from the China Research Data Service Platform (CNRDS) database, city-level data are from the China City Statistical Yearbook, and the rest of the data are from the Cathay Pacific (CSMAR) database.

2.2 Variables

i. Dependent variable

Following Cai et al. (2020), we categorize green patents into green invention patents and utility model patents. Green utility model patents are associated with strategic innovation and indicate low-level innovation to meet government standards. Green invention patents are associated with substantial innovation and are a more effective indicator of a firm's substantial green innovation and sustainability. We use the number of green patent applications and the number of green invention patent applications to measure the level of firms' substantive green innovation. The scale of green patent applications includes $Patent_{it}$

and $invPatent_{it}$, which represent the logarithm of firms' green patents and green invention patents, respectively. In our robustness tests, we use $rPatent_{it}$ and $rinvPatent_{it}$ as our proxy measures. $rPatent_{it}$ represents the proportion of green patent applications (green invention patent applications) to all patent applications in a year.

ii. Independent variable

The Chinese government launched the pilot list of low carbon cities in 2010, 2012 and 2017, so $Policy_{rt}$ represents a low carbon city after these three time points. If yes, it will be recorded as 1, otherwise it will be 0.

iii. Internal and external factor variables

We selected both internal and external factors as variables. Internal is $Acadbg_{it}$ which represents whether the business executive has a PhD degree and whether he/she has worked in a school or a research organization. If yes, it is recorded as 1 and if no it is recorded as 0. The external factor is Gsu_{it} (the logarithm of the number of government environmental subsidies).

iv. Control variables

Based on existing research on the greening of companies, we have specified the following factors that may affect their development: age, $size$, $debt$, $tobinQ$, roa, $capinten$, $independent$.

2.3 Model Construction

As of 2020, China has promoted three batches of LCCP policy pilots, providing a good quasi-natural experimental environment for this paper. Since the LCCP policies span multiple periods and affect firms differently, we mainly adopt the staggered difference-in-difference (DID) for testing. In this paper, we mainly refer to the method proposed by Cui (2018), and the model is as follows:

$$Patent_{it}/invPatent_{it} = \beta_0 + \beta_1 Policy_{rt} + \beta_2 \sum Controls_{it} + \gamma_t + \alpha_i + \varepsilon_{it}$$

We divide the experimental data into two groups: one is the experimental group (firms under the influence of LCCP policy) and the other is the control group (firms not affected by LCCP policy). In addition, $Patent_{it}/invPatent_{it}$ represents the logarithm of the number of green patents or green inventions filed by firm i in year t. This can be regarded as a measure of environmental innovation. This can be regarded as a measure of environmental innovation. $Policy_{rt}$ represents whether the firm is affected by the LCCP policy or not, and r represents the region, which is 1 if it is, and 0 if it is not. γ_t, α_i are the parameters controlling for time and firm fixed effects, respectively, and ε_{it} is a disturbance variable that is not accounted for in the observation.

Based on this, we will investigate the effects of internal and external factors on the model, thus introducing $Acadbg_{it}$ (a dummy variable representing whether the executives have taught in universities and whether they have a PhD degree) and Gsu_{it} (representing government subsidies), and the modified model is as follows:

$$Patent_{it}/invPatent_{it} = \beta_0 + \beta_1 Policy_{rt} + \beta_2 Acadbg_{it} + \beta_3 Policy_{rt} \times Acadbg_{it} + \beta_4 \sum Controls_{it} + \gamma_t + \alpha_i + \varepsilon_{it}$$

$$Patent_{it}/invPatent_{it} = \beta_0 + \beta_1 Policy_{rt} + \beta_2 Gsu_{it} + \beta_3 Policy_{rt} \times Gsu_{it} + \beta_4 \sum Controls_{it} + \gamma_t + \alpha_i + \varepsilon_{it}$$

3 Results

3.1 Baseline results

The first two columns of table 2 presents the baseline findings. Our specifications include time and firm fixed effects. In Column (1), the results reveal a significant and positive impact of LCCP on corporate green innovation (Patents) ($\beta1=0.015$, $p < 0.1$), indicating a noteworthy promotion of corporate green innovation by LCCP. Moreover, Column (2) demonstrates a significantly positive coefficient of Policy ($\beta1=0.016$, $p < 0.1$), suggesting that the LCCP policy notably encourages applications for green invention patents. These results collectively underscore the constructive role of the LCCP policy in fostering substantive green innovation.

	(1)	(2)	(3)	(4)
VARIABLES	**Patent**	**invPatent**	**rPantent**	**rinvPatentit**
Policy	0.015*	0.016*	0.002	0.002
	(0.007)	(0.009)	(0.002)	(0.002)
age	0.043***	0.021**	-0.001	0.002
	(0.010)	(0.008)	(0.002)	(0.001)
size	0.057***	0.053***	-0.004***	-0.002
	(0.008)	(0.007)	(0.001)	(0.001)
debt	0.017	0.027	-0.013**	-0.005
	(0.032)	(0.026)	(0.006)	(0.004)
tobinQ	-0.039**	-0.019	-0.006**	-0.005**
	(0.016)	(0.013)	(0.003)	(0.002)
roa	-0.015	-0.021	-0.015*	-0.008
	(0.049)	(0.041)	(0.009)	(0.007)
capinten	-0.013***	-0.010***	-0.000	-0.000
	(0.004)	(0.003)	(0.001)	(0.001)
independent	0.074	0.058	-0.016	-0.011
	(0.081)	(0.067)	(0.014)	(0.011)
Observations	27,810	27,810	27,810	27,810
R-squared	0.680	0.659	0.437	0.379
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES

Table 2

3.2 Robustness test

3.2.1 Parallel trend test

The fundamental assumption underlying the staggered DID model is the satisfaction of the parallel trend's assumption. In our context, this assumption implies that, prior to the implementation of the LCCP policy, a consistent time trend is observed in green patent applications among firms in pilot cities and those in non-pilot cities, which then diverges following policy implementation. Figure 1 illustrates the estimated coefficients of the interaction terms before and after the implementation of the LCCP policy. It indicates that the estimated difference between firms in low-carbon and non-low-carbon cities is not statistically significant during the pre-treatment period, supporting the parallel trend assumption. Moreover, following policy implementation, this estimated difference significantly increases. These findings suggest that, before policy implementation, there was no significant trend in the change of green patent applications among firms in low-carbon cities compared to benchmark firms. However, post-policy implementation, there is a notable upward trend in green patent applications among firms in low-carbon cities, with coefficients significantly differing from zero. In summary, the validation of the parallel trend assumption in the staggered DID model is supported by the significant coefficients observed in the years following policy implementation.

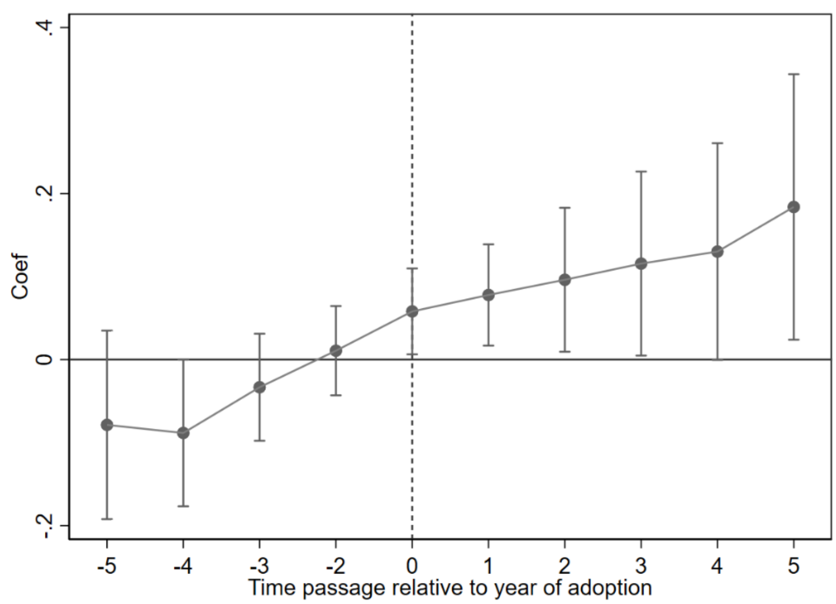

Fig 1

3.2.2 Replacing dependent variable

To further validate the results of the baseline regression, we replaced the dependent variable in the equation. We used the corresponding proportion of green patent applications to evaluate the impact of the LCCP policy on this measure. The results are presented in columns (3) and (4) of Table 2. However, unlike the original article, we did not observe significant results. It's worth acknowledging that the lack of significance in certain cases may stem from differences in data sources. The total patent data used as the denominator in the proportion and the green patent data used as the numerator may come from different sources. Additionally, the limited quantity of substantive green innovation instances may exacerbate this issue, particularly when considering logarithmic transformations, which can further reduce numerical values.

3.3 Mechanism test

3.3.1 Internal factor: academic executive

The influence of executives' personality traits and prior experiences on corporate strategic decisions may alter the effectiveness of the LCCP policy. Academic executives, in particular, often possess extensive knowledge, long-term perspectives, and unique insights. Consequently, they are more inclined to prioritize sustainable development and innovative transformations and are likely to exhibit greater willingness to comply with the LCCP policy. Moreover, academic executives tend to have stronger moral sentiments and place greater emphasis on social reputation. The environmentally friendly nature of the LCCP policy makes it easier to exert moral and reputational pressure on them, compelling them to enact the policy. Thus, we introduce an internal factor variable represented by a dummy variable ($Acadbg_{it}$) to examine its impact.

Table 3 presents the findings. Columns (1) and (2) display the regression outcomes concerning the moderating effect of academic executives. The coefficients of $Policy_{rt}$ $\times Acadbg_{it}$t, signifying the interaction term, are both significantly positive (β3=0.059, $p <$ 0.01; β3=0.059 $p < 0.01$). This indicates that internal academic executives positively moderate the promotional impact on corporate substantive green innovation.

	(1)	(2)
VARIABLES	**Patent**	**invPatent**
1.Policy	0.014	0.012
	(0.013)	(0.011)
1.Acadbg	0.01	0.015
	(0.012)	(0.010)
1.Policy#1.Acadbg	0.059***	0.059***
	(0.015)	(0.013)
Controls	YES	YES
Observations	27,810	27,810
R-squared	0.681	0.659
Year FE	YES	YES
Firm FE	YES	YES

Table 3

3.3.2 External factor: government environmental subsidy

Government environmental subsidies, comprising financial support allocated by the government to firms for environmental protection and governance activities, play a crucial role in incentivizing green initiatives. These subsidies aid in financing the establishment of environmental protection facilities, which typically require substantial capital and resources. Consequently, highly polluting firms may exhibit less reluctance towards undertaking green innovation. By providing additional green funds to firms, government environmental subsidies create favorable conditions for the LCCP policy to stimulate corporate green innovation. Moreover, these subsidies can enhance a firm's environmental image, potentially improving its standing with investors.

To assess their impact, we employed the variable Gsu_{it}. Table 4 presents the findings regarding government environmental subsidies. Columns (1) and (2) demonstrate that the coefficients of $Policy_{rt} \times Gsu_{it}$ are both significantly positive (β3=0.023, $p < 0.1$; β3=0.022, $p < 0.1$), indicating that external government environmental subsidies enhance the effectiveness of the LCCP policy in promoting corporate green innovation.

	(1)	(2)
VARIABLES	**Patent**	**invPatent**
1.Policy	0.013	0.018*
	(0.012)	(0.010)
1.Gsu	0.009	0.014
	(0.011)	(0.009)
1.Policy#1.Gsu	0.023*	0.022*
	(0.011)	(0.01)
Controls	YES	YES
Observations	27,810	27,810
R-squared	0.681	0.659
Year FE	YES	YES
Firm FE	YES	YES

Table 4

3.4 Heterogeneity analysis

3.4.1 Urban geographical character

In terms of geographical location, cities in the eastern region typically boast more advanced technology, convenient transportation networks, and a diverse cultural landscape. The abundance of knowledge reserves and robust infrastructure in these areas provides a solid foundation for firms to pursue green innovation. Therefore, we anticipate that the impact of the LCCP policy on green innovation will be more pronounced for firms located in the eastern region.

To assess the influence of urban geographical characteristics on the effectiveness of the LCCP policy, we employed the following treatment procedure: the sample was divided into eastern and central or western regions based on geographical location. Table 5 illustrates that the coefficients o $Policy_{rt}$ are only significantly positive (β1=0.028, $p < 0.1$; β1=0.022, $p < 0.1$) within the samples from the eastern region. This suggests that the LCCP policy significantly promotes green innovation among firms situated in cities in the eastern region.

	(1)	(2)	(3)	(4)
VARIABLES	**Patent Eastern**	**Patent Central/Western**	**invPatent Eastern**	**invPatent Central/Western**
Policy	0.028*	-0.012	0.022*	0.003
	(0.014)	(0.020)	(0.012)	(0.016)
age	0.053***	0.024	0.028***	0.004
	(0.012)	(0.019)	(0.010)	(0.016)
size	0.063***	0.043***	0.062***	0.034***
	(0.010)	(0.014)	(0.009)	(0.011)
debt	-0.028	0.107*	-0.017	0.116***
	(0.039)	(0.055)	(0.033)	(0.045)
tobinQ	-0.033*	-0.057**	-0.007	-0.051**
	(0.020)	(0.028)	(0.017)	(0.023)
roa	-0.032	0.049	-0.039	0.050
	(0.057)	(0.099)	(0.047)	(0.081)
capinten	-0.015***	-0.006	-0.014***	-0.003
	(0.005)	(0.007)	(0.004)	(0.005)
independent	0.253**	-0.273**	0.222***	-0.253**
	(0.102)	(0.134)	(0.084)	(0.110)
Observations	19,201	8,609	19,201	8,609
R-squared	0.690	0.657	0.671	0.628
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES

Table 5

3.4.2 Nature of ownership

We proceed to investigate whether state ownership affects the effectiveness of the LCCP policy on corporate green innovation. State-Owned Enterprises (SOEs), compared to non-SOEs, typically maintain closer ties with the government. The potential collusion between SOEs and local governments may introduce ambiguity in the implementation of the LCCP policy within SOEs. Additionally, government officials facing promotion pressures might prioritize SOEs' contributions to Gross Domestic Product (GDP) over green innovation. Furthermore, SOEs, being generally larger than non-SOEs, often benefit from more substantial financial subsidies and tax breaks. Consequently, SOEs, which possess ample resources and technology, may lack the incentive to pursue green transformation through the financial and technical support provided by the LCCP policy.

To explore this, we divided our sample into SOEs and non-SOEs and examined whether the effectiveness of the LCCP policy varied based on the nature of ownership.

Table 6 presents the findings. Columns (2) and (4) indicate that the impact of the LCCP policy on corporate green innovation is only positive and significant ($\beta 1=0.034$, $p < 0.05$; $\beta 1=0.027$, $p < 0.05$) among non-SOEs. This suggests that the LCCP policy is more conducive to promoting substantive green innovation in firms subject to weaker external supervision.

VARIABLES	(1) Patent SOEs	(2) Patent Non_SOEs	(3) invPatent SOEs	(4) invPatent Non_SOEs
Policy	-0.024	0.034**	-0.009	0.027**
	(0.017)	(0.016)	(0.014)	(0.012)
age	0.090***	0.063***	0.055***	0.044***
	(0.020)	(0.013)	(0.018)	(0.010)
size	0.063***	0.079***	0.062***	0.069***
	(0.013)	(0.011)	(0.012)	(0.009)
debt	0.007	-0.015	0.028	-0.005
	(0.051)	(0.042)	(0.044)	(0.034)
tobinQ	-0.068**	0.011	-0.029	0.012
	(0.028)	(0.021)	(0.024)	(0.016)
roa	-0.136	-0.004	-0.092	-0.021
	(0.099)	(0.058)	(0.086)	(0.046)
capinten	-0.014**	-0.014***	-0.013**	-0.010***
	(0.006)	(0.005)	(0.005)	(0.004)
independent	0.136	-0.025	0.087	-0.011
	(0.116)	(0.116)	(0.101)	(0.092)
Observations	11,662	16,116	11,662	16,116
R-squared	0.689	0.681	0.657	0.669
Year FE	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES

Table 6

4 Further discussion

4.1 New baseline results

After completing the model regression as outlined in the original article, we realized that inconsistencies in results may arise due to different data sources. To enhance the rigor of our regression analysis, we made the following adjustments:

i. Inclusion of Provincial Fixed Effects: To mitigate the impact of environmental policies varying across provinces.

ii. Clustering of Results at the Industry Level: Results are clustered according to the major categories of the Industrial Classification for National Economic Activities (with clustered standard errors provided in parentheses) to eliminate potential disparities in patent growth rates across different industries.

The updated results are presented in Table 7. It can be observed that, compared to the baseline results, controlling for provincial fixed effects has yielded more pronounced findings.

VARIABLES	(1) Patent	(2) invPatent
Policy	0.017*	0.019*
	(0.008)	(0.008)
age	0.041	0.020
	(0.035)	(0.036)
size	0.060***	0.056***
	(0.016)	(0.018)
debt	0.018	0.026
	(0.035)	(0.027)
tobinQ	-0.038***	-0.017
	(0.012)	(0.011)
roa	-0.019	-0.025
	(0.035)	(0.025)
capinten	-0.013***	-0.011***
	(0.003)	(0.002)
independent	0.071	0.056
	(0.058)	(0.059)
Observations	27,810	27,810
R-squared	0.681	0.659
Year FE	YES	YES
Firm FE	YES	YES
Province FE	YES	YES

Table 7

4.2 Additional heterogeneity analysis

Following the heterogeneity analysis referred to in the literature (Li, Y. H., 2023), we conducted additional heterogeneity analysis. Enterprises were classified into different lifecycle stages to further investigate the impact of pilot policies on green technological innovation among manufacturing enterprises. Specifically, enterprises with an age of ≤6 years were categorized as startups, those with an age of >6 years and ≤12 years were classified as growth-stage enterprises, and those with an age of >12 years were classified as mature-stage enterprises. As shown in Table 8, the policy significantly promotes green technological innovation among growth-stage and mature-stage manufacturing enterprises, while its effect on startups in the manufacturing sector is not significant. This may be attributed to startups in the manufacturing sector allocating most of their funds towards expanding production capacity to gain more market share, rather than investing in high-cost, high-risk green technological innovation projects.

VARIABLES	(1) Patent Initial stage	(2) Patent Growth stage	(3) Patent Mature period
Policy	-0.024	0.026*	0.028*
	(0.051)	(0.014)	(0.014)
size	-0.009	0.129***	0.034***
	(0.088)	(0.026)	(0.010)
debt	0.214	-0.118	0.026
	(0.198)	(0.086)	(0.040)
tobinQ	-0.056	0.004	-0.026
	(0.077)	(0.034)	(0.022)
roa	-0.667	-0.275**	-0.050
	(0.484)	(0.128)	(0.057)
capinten	-0.020	-0.034***	-0.007
	(0.024)	(0.010)	(0.005)
independent	0.268	-0.050	0.120
	(0.361)	(0.195)	(0.100)
Observations	4,060	7,413	15,578
R-squared	0.864	0.762	0.730
Year FE	YES	YES	YES
Firm FE	YES	YES	YES

Table 8

5 Conclusion

The LCCP policy is a city-based policy that promotes the overall achievement of carbon peaking and carbon neutrality, thus stimulating enterprises to continuously innovate and reduce carbon emissions. Based on the green patent application data of A-share listed enterprises, this paper empirically analyzes the impact of LCCP policy on enterprises' green technological innovation and its functioning mechanism by using the interleaved DID model method. The main conclusions are as follows:

i. Compared with the companies under the influence of non-LCCP policy, the companies under LCCP policy significantly increase the development and research on green innovation technology, i.e. green patents. In other words, the LCCP policy has a significant positive effect on the green technology innovation of enterprises. After completing a series of robustness tests, the above conclusion still holds.

ii. The mechanism test shows that under the dual influence of academic support as well as financial subsidies, it will greatly promote enterprises to realize green technological innovation.

iii. From the viewpoint of the region where the enterprises are located, the promotion effect of LCCP policy on the green technology innovation of the enterprises in the eastern region is significantly higher than that of the manufacturing enterprises in other regions; from the viewpoint of the nature of enterprise property rights, the promotion effect of LCCP policy on the green technology innovation of the non-state-owned manufacturing enterprises is significantly higher than that of the state-owned manufacturing enterprises.

This paper has important insights for further promoting the LCCP policy and promoting green technological innovation of enterprises:

i. The government should rationally utilize the positive impact effect of LCCP policy on green patent applications, fully consider the synergistic effect of compliance and regulatory effects, vigorously strengthen the construction of cities under the LCCP policy, and effectively bring into play the incentive effect of LCCP policy.

ii. Pay attention to regional heterogeneity as well as enterprise heterogeneity. Enterprises in non- eastern regions should formulate reasonable policies according to local conditions. For different types of enterprises of different ages, there should be targeted policies, so as to maximize the incentive effect of LCCP policy.

iii. Focus on improving supporting subsidy policies for green technology innovation enterprises, such as financial subsidies, talent introduction, policy priority, etc., to strengthen the LCCP policy to promote green patent applications, enhance business confidence, in order to achieve the reduction of carbon emissions, and to mitigate the environmental impact of the problem.

Overall, this paper demonstrates the significant impact of LCCP policy on various types of listed companies through a series of studies, providing a perspective for realizing interdisciplinary research. We also demonstrate the effectiveness of environmental regulatory policies, supporting the controversial Porter’s hypothesis in emerging markets. In addition, the effects of development of enterprises under the influence of various types of subsidy policies provide research directions for policymakers, implementers in enterprises, and scholars.