

Low Carbon City Pilot Policy and Corporate Innovation

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Abstract: The "Double Carbon" target cannot be achieved without energy saving and carbon reduction in urban units, and corporate innovation is indispensable for cities to achieve energy saving and carbon reduction. Based on the data of Chinese A-share firms listed on Shanghai and Shen Stock Exchange over the period of 2007–2020, this paper explores the impact of low-carbon city pilot policies on enterprise innovation using the DDD method, and further refines the substantive and strategic aspects of the impact on enterprise innovation, and explores the heterogeneity of enterprise ownership nature and size. The study finds that, first, the pilot low-carbon city policy significantly promotes corporate innovation and has a slightly higher positive incentive effect on substantive innovation than strategic innovation. Second, non-state corporations and large-scale corporations tend to enhance substantive innovation while state-owned corporations and small-scale corporations tend to engage in strategic innovation activities as a result of the pilot policy.

Keywords: Low Carbon City Pilot Policy; Corporate Innovation; DDD.

1. Introduction

At present, the global climate change situation is becoming increasingly serious, and countries around the world have made a series of policy actions to actively implement carbon emission reduction targets. China has always attached great importance to carbon emission reduction and low-carbon development, and has been implementing the low-carbon city pilot policy since 2010, and has carried out three batches of pilot projects covering 87 provinces and cities, accumulating and forming a number of replicable and replicable experiences. The 20th Party Congress further strengthened the strategic deployment of "carbon peaking and carbon neutral", demonstrating China's firm confidence in achieving the goal of "Double Carbon". In February 2021, the State Council issued the "Guiding Opinions on Accelerating the Establishment and Improvement of a Green Low-carbon Circular Economic System", in June 2022, the nine departments of the Ministry of Science and Technology jointly developed the "Implementation Plan for Science and Technology Supporting Carbon Peak Carbon Neutralization (2022-2030)", and in December of the same year, the National Development and Reform Commission and the Ministry of Science and Technology issued the "Implementation Plan for Further Improving the Market-oriented Green Technology Innovation System (2023-2025)". The release of these documents emphasizes the key role of technological innovation in supporting green and low-carbon development. Therefore, it is necessary for this paper to explore the relationship between low-carbon city pilot policies and corporate innovation in the above context.

The possible contributions of this paper are mainly in the following three areas:

First, as the application of environmental regulation policies continues to expand and their impact on the corporate level deepens, previous studies have mostly focused on the impact of environmental regulation policies on corporate economic performance (e.g., corporate value [1], corporate investment efficiency[2], and corporate total factor productivity[2]) and environmental performance (e.g., emission reduction effects [4]), while this paper takes the

perspective of the impact of environmental regulation policies on corporate innovation. This paper further enriches the empirical evidence of the Porter hypothesis;

Second, while previous studies on innovation have focused on property rights protection[5], reduction of financing constraints[6], and agency problems[7], this paper examines the impact of pilot policies on innovation in low-carbon cities from the perspective of environmental regulation, and further distinguishes between substantive and strategic innovation based on a motivational perspective, which has certain practical implications for government policy formulation and corporate strategic arrangements.

The rest of the paper is organized as follows. The second section is a literature review. Section 3 presents the research design, including data sources, variable selection and model design, and descriptive statistics. Section 4 presents the empirical results. Section 5 presents the discussion and conclusion.

2. Literature Review and Hypothesis Development

2.1. Environmental Regulation and Corporate Innovation

As resources are scarce, the use of environmental resources inevitably generates externalities, and the concept of environmental regulation is developed precisely in the process of exploring how to overcome the negative externalities of environmental pollution. Since Dasgupta first proposed the concept of environmental regulation in 1980, many scholars at home and abroad have expanded on the subject of environmental regulation, the means of regulation and the ultimate purpose of environmental regulation, etc. At the beginning of the 21st century, Chinese scholars gradually began to pay attention to the issue of environmental regulation and further expanded its meaning. Among them, whether environmental regulation can promote enterprise innovation has been controversial, and most of the existing literature is based on the "Porter hypothesis", which can be divided into three categories. The first type of conclusion supports that environmental regulation can promote firm

innovation, and that reasonable environmental regulation will produce "innovation compensation effect", which will stimulate firms to innovate, thus increasing their productivity and ultimately maximizing their benefits[8][9][10][11][12]. The second type of findings supports that environmental regulation inhibits firm innovation, arguing that environmental regulation has a "compliance cost effect" that increases the cost of pollution control, which may lead firms to reduce their R&D investment in the short term and may also choose to relocate to areas with relatively lax environmental regulations, resulting in pollution transfer [13] [14]. The third type of findings indicates that there is uncertainty in the impact of environmental regulation on firm innovation, and there may be non-linear characteristics between the two[15] [16] or no significant relationship[17].

2.2. Low-carbon City Pilot Policy

Academic research related to low-carbon cities is divided into two main directions: firstly, it focuses on the low-carbon attributes of cities, and explores the policy design[18], the current progress[19][20] and the construction of the evaluation system[21] of low-carbon cities. Second, the effects of pilot policies of low-carbon cities are evaluated, and some studies find that pilot policies of low-carbon cities can effectively promote carbon emission reduction and air environment improvement[22][23][24][25][26][27], and some studies find that pilot policies of low-carbon cities have positive effects on foreign direct investment[28], industrial structure upgrading[29], and total factor productivity [30] [31] [31] have produced positive indirect impact effects, and in addition, some studies have also started to focus on innovation, attempting to further analyze the impact of low-carbon city pilot policies on corporate green technology innovation from a micro perspective at the firm level[33][34].

2.3. Hypothesis Development

Since the "Porter's hypothesis" was proposed, many domestic and foreign scholars have conducted a lot of research based on the actual environmental regulation policies in their countries, and the question of whether environmental regulation can promote corporate innovation has become a key research area. In order to verify the existence of Porter's hypothesis in the relationship between environmental regulation and corporate innovation, many scholars have conducted empirical studies. Some of the studies do confirm the existence of the Porter hypothesis[35][36]. However, some studies found that the Porter hypothesis may not be valid due to certain factors, such as weak market sophistication, poor policy design and implementation, and regional endowment differences[37]. Thus, environmental regulations may have a negative "compliance cost effect" on corporate innovation investment on the one hand, and a positive "innovation compensation effect" on the other. The pilot low-carbon city policy as an environmental regulation policy also has two effects on firm innovation. Specifically, the Porter hypothesis suggests that the implementation of environmental regulation policies can increase firms' investment in environmental protection activities. With the introduction of the low-carbon city pilot policy, the increasingly stringent environmental regulations will force corporations to engage in technological innovation, and as the cost of pollution treatment increases, it will be more beneficial to engage in technological innovation. Pilot policies may motivate corporations to innovate and achieve a

win-win situation for both the economy and the environment [35]. In contrast, the traditional theory of neoclassical hypothesis suggests that the proposed low-carbon city pilot policy makes the environmental pollution control standards in the pilot areas tighten, which means that polluting industries and corporations have to invest a large amount of capital and human resources in reducing pollution and carbon, and the cost of pollution control will increase in the short term, which tends to curtail innovation investment under a certain level of capital and has a negative impact on corporate innovation[38][39].Based on the above analysis, it is found that the implementation of low-carbon city pilot policies may have both promotional and inhibitory effects on corporate innovation, according to which, this paper proposes the hypothesis that

H1a: The implementation of low-carbon city pilot policies may promote corporate innovation

H1b: The implementation of low-carbon city pilot policies may inhibit corporate innovation

3. Research Design

3.1. Sample Selection

The sample consists of Chinese A-share firms listed on Shanghai and Shen Stock Exchange over the period of 2007–2020. Since the low-carbon city pilot policy started from 2010 and then gradually expanded the scope of the pilot, the year 2012 will be taken as the time point for external policy shocks. The data is retrieved from the China Stock Market and Accounting Research (CSMAR) database. Listed companies registered in the pilot provinces are the treatment group, while listed companies registered in the non-pilot provinces are set as the control group. In order to ensure the validity of the data processing results, this article screens the samples as follows: (1) excluding the financial firms; (2) excluding ST/PT firms; (3) excluding observations with missing financial data. Finally, a total of 646 listed firms were included, with a total of 35261 samples. The sample selection process is presented in Table 1.

Table 1. Variable and definition.

Variable	Measurement
PATENT	Log (1+Invention+Utility Model+Design)
IPATENT	Log(1+Invention)
UDPATENT	Log (1+Utility Model+Design)
Pilot	city or province belongs to the first two batches of pilot policy area & year >= 2010 or 2012, Pilot=1; otherwise, =0
Size	Log (total asset value)
Leverage	total liabilities / total assets
ROA	net profit for the period / total assets at the end of the period
TobinQ	Market value/replacement value
PPE	net fixed assets / total assets
SOE	the actual controller of the enterprise is defined as 1 by the central or local government, if not as 0
CFO	net cash flow from operating activities / total assets
TOP1	Largest shareholder rate
INST	Institution

3.2. Model and Variable

In this paper, the low-carbon city pilot policy is used as a quasi-natural experiment. We draw on the research of Deschênes (2017) [41] to examine the impact of low carbon city pilot policies on corporate innovation by constructing a DDD (Difference in Difference in Difference) model. The model is set up as follows:

$$Innovation_{it} = \beta_1 Post_t * Pilot_r * Indpollution_j + \beta X_{it} + \delta_{rt} + \mu_{jt} + \lambda_{rj} + \eta_i + \varepsilon_{ijrt} \quad (1)$$

$Innovation_{it}$ is the explained variable, which indicates corporate innovation. In this paper, the number of patents applied for and granted is used as proxies for corporate innovation output. The number of patents applied for and granted is the natural logarithm of the total number of designs, utility model and invention patents applied for and granted by the corporation each year, and the variable symbol is represented by $PATENT$. What's more, according to the study of Tong et al. (2014), $IPATENT$ and $UDPATENT$ are used to denote substantive innovation and strategic innovation respectively[40].

The explanatory variables include a time dummy ($Post_t$), a region dummy ($Pilot_r$), and an industry attribute variable ($Indpollution_j$). Among them, $Pilot_r$ indicates a value of 1 if it is a pilot area of a low-carbon city and 0 if it is not; $Post_t$ indicates a value of 1 if it is after the pilot year (2012) and 0 if it is before the pilot time; $Indpollution_j$ indicates a value of 1 if the industry to which the company belongs is a heavy polluter and 0 if it is not. The coefficient β_1 of $Post_t * Pilot_r * Indpollution_j$ is a triple difference estimator representing the impact on corporate innovation between pilot and non-pilot regions and between heavily polluting and non-heavily polluting industries before and after the implementation of the low-carbon city pilot policy. If β_1 is significantly positive, it indicates that the pilot policy helps to promote the innovation activities of heavily polluting corporations in the pilot areas.

This paper draws on Hu et al. (2020) to select a set of control variables (X_{it}), such as corporate size ($Size$), financial leverage ($Leverage$), net asset margin (ROA), market value / replacement value ($TobinQ$), nature of ownership (SOE), investment in fixed assets (PPE), cash level (CFO), Largest shareholder rate ($TOP1$) and Institution ($INST$)[42]. In addition, the fixed effects of industry change over time were denoted as μ_{jt} and province change over time was denoted as δ_{rt} , region-industry fixed effects was denoted as λ_{rj} , η_i was denoted as corporate fixed effect, ε_{ijrt} is a random interference term.

The descriptive statistics of each variable are shown in Table 2. In terms of the overall level, the mean value of the number of patent applications filed and granted ($PATENT$) of the sample corporations is 0.390 with a standard error of 1.078, which means that the overall innovation level of the sample corporations is not high and there is a large difference in the total amount of innovation among the corporations. From the classification of innovation motives, the mean value of the number of invention patents applied for and granted ($IPATENT$) of the sample corporations is 0.320, while the mean value of the number of utility model and design patents applied for and granted ($UDPATENT$) of the corporations is 0.185. The level of substantive innovation is slightly higher than the level of strategic innovation, representing that the corporations are paying more attention to high-quality innovation in recent years. However, there is a problem of low

level of both substantive and strategic innovation.

Table 2. Descriptive statistics

Variable	N	Mean	SD	p25	p50	p75
PATENT	35261	0.390	1.078	0.000	0.000	0.000
IPATENT	35261	0.320	0.925	0.000	0.000	0.000
UDPATENT	35261	0.185	0.707	0.000	0.000	0.000
Leverage	35261	0.427	0.208	0.260	0.420	0.585
ROA	35261	0.038	0.064	0.015	0.039	0.069
PPE	35261	0.217	0.164	0.088	0.183	0.310
Size	35261	22.041	1.296	21.098	21.859	22.783
TobinQ	34074	2.025	1.284	1.249	1.613	2.291
SOE	35261	0.378	0.485	0.000	0.000	1.000
CFO	35261	0.047	0.073	0.007	0.047	0.089
INST	35261	0.448	0.247	0.249	0.469	0.644
Top1	35261	35.017	15.053	23.140	32.990	45.230

4. Empirical Result

4.1. Regression Result

The regression results in Table 3 show that after controlling for province, industry, and time fixed effects, the coefficients of the triple difference terms are all significantly positive at the 1% level, which implies that the low-carbon city pilot policy has a positive incentive effect on the overall level of innovation, the level of substantive innovation, and the level of strategic innovation of enterprises in the heavy pollution industry in the pilot area, verifying the existence of hypothesis H1a. Further distinguishing firms' innovation motives, it is found that the low-carbon city pilot policy has a slightly higher positive incentive effect on substantive innovation than strategic innovation.

Table 3. Regression results

	PATENT	IPATENT	UDPATENT
Post Pilot Indpollution	0.106*** (3.76)	0.081*** (3.30)	0.068*** (3.69)
Size	0.031*** (4.62)	0.042*** (7.03)	-0.017*** (-4.30)
ROA	0.455*** (4.73)	0.400*** (4.86)	0.229*** (3.55)
PPE	-0.267*** (-6.68)	-0.268*** (-7.79)	-0.058** (-2.20)
Leverage	-0.236*** (-6.73)	-0.194*** (-6.47)	-0.087*** (-3.69)
TobinQ	-0.006 (-1.20)	0.003 (0.61)	-0.014*** (-3.98)
SOE	-0.014 (-1.03)	0.009 (0.76)	-0.054*** (-6.29)
CFO	-0.009 (-0.11)	-0.010 (-0.14)	0.007 (0.12)
INST	0.061* (1.83)	0.072** (2.57)	0.003 (0.12)
Top1	-0.001** (-1.97)	-0.001*** (-2.78)	-0.000 (-0.47)
cons	-0.485*** (-3.38)	-0.751*** (-5.91)	0.430*** (5.27)
Industry	Yes	Yes	Yes
Year	Yes	Yes	Yes
N	34074	34074	34074
Adjusted R2	0.047	0.045	0.033
F	66.565	62.717	36.109

t statistics in parentheses; * p < 0.1, ** p < 0.05, *** p < 0.01; ***1% **5% *10%

4.2. Heterogeneity Analysis

Since the different ownership nature will have different effects on the ease of access to resources, this paper divides the corporations into state-owned and non-state-owned corporations and examines the effects of the low-carbon city pilot policy on the overall level of innovation, substantive and strategic innovation of the two types of corporations respectively. The results in Table 4 show that, in terms of overall innovation level, the pilot low-carbon city policy has a positive incentive effect on both types of corporations, with a slightly higher impact on state-owned corporations than non-state-owned corporations, probably because on the one hand, state-owned enterprises are less likely to face financing constraints and thus have sufficient funds for innovation activities in the face of tightening environmental policies, and on the other hand, state-owned corporations have a higher social responsibility due to their state-owned status and thus have to take the lead in innovation in the face of environmental regulations. Further differentiating the motivations for innovation shows that non-state-owned corporations show higher motivation for substantive innovation, while state-owned corporations tend to innovate more strategically, probably because non-state-owned corporations are more flexible in their organizational composition and face more severe market competition, and thus tend to innovate substantively for technological improvement, while state-owned corporations are more complex in their organizational composition and less likely to transform their existing technologies quickly, and thus tend to innovate strategically to meet policy needs.

Table 4. Heterogeneity Analysis1: by nature of ownership

	State-owned enterprises		
	PATENT	IPATENT	UDPATENT
Post Pilot Indpollution	0.100**	0.073*	0.085***
	(2.30)	(1.89)	(3.20)
Industry	Yes	Yes	Yes
Year	Yes	Yes	Yes
N	13076	13076	13076
Adjusted R2	0.060	0.060	0.026
F	24.321	22.695	11.378
	Non-State-Owned Enterprises		
	PATENT	IPATENT	UDPATENT
Post Pilot Indpollution	0.097***	0.075**	0.062**
	(2.63)	(2.35)	(2.48)
Industry	Yes	Yes	Yes
Year	Yes	Yes	Yes
N	20998	20998	20998
Adjusted R2	0.040	0.038	0.031
F	47.272	44.114	27.835

t statistics in parentheses; * p < 0.1, ** p < 0.05, *** p < 0.01; ***1% **5% *10%

In addition, there are differences in the relative advantages possessed by corporations of different sizes, thus this paper draws on Liu et al. (2022)[43] to classify corporations into two categories, large-scale and small-scale, and examine the heterogeneous effects of low-carbon city pilot policies on the two categories of corporations separately. From the results in Table 5, it can be seen that the effects of the low-carbon city pilot policy on innovation of small-scale and large-scale firms are significantly positive at the 10% and 1% levels, respectively, in terms of overall level of innovation, substantive and strategic level of innovation. Moreover, large-scale corporations show higher motivation than small-scale

corporations in general and at the classification level, which may be due to the fact that large-scale corporations face fewer financial difficulties and have a better technological R&D base and capability than small-scale corporations.

Table 5. Heterogeneity Analysis 2: by corporate size

	Small Scale		
	PATENT	IPATENT	UDPATENT
Post Pilot Indpollution	0.075*	0.066*	0.042*
	(1.83)	(1.81)	(1.68)
Industry	Yes	Yes	Yes
Year	Yes	Yes	Yes
N	15312	15312	15312
Adjusted R2	0.049	0.050	0.025
F	34.332	32.600	15.460
	Large Scale		
	PATENT	IPATENT	UDPATENT
Post Pilot Indpollution	0.132***	0.095***	0.095***
	(3.43)	(2.93)	(3.54)
Industry	Yes	Yes	Yes
Year	Yes	Yes	Yes
N	18762	18762	18762
Adjusted R2	0.053	0.048	0.044
F	36.988	34.231	23.131

t statistics in parentheses; * p < 0.1, ** p < 0.05, *** p < 0.01; ***1% **5% *10%

5. Conclusion

The realization of the "Double Carbon" goal cannot be achieved without energy and carbon reduction in urban units, which in turn cannot be achieved without the boosting effect of enterprise innovation. This paper explores the impact of low-carbon city pilot policies on corporate innovation using the DDD method based on firm-level micro data, and concludes that low-carbon city pilot policies can positively stimulate corporate innovation; when innovation motivation is further considered, low-carbon city pilot policies have a slightly higher stimulating effect on substantive innovation than strategic innovation; in terms of firm heterogeneity, low-carbon city pilot policies have different impact effects on firms with different ownership nature and different scales. Specifically, non-state-owned and large-scale corporations tend to enhance their substantive innovation level under the incentives of pilot policies, while state-owned and small-scale corporations tend to engage in strategic innovation activities.

Based on the above findings, this paper draws the following policy implications: First, the pilot policy of low-carbon cities has the characteristics of early and pilot implementation, following the principle of further promotion on the basis of accumulated experience, which has effectively promoted the improvement of the innovation level of corporations in the pilot areas. Therefore, the top-level design of the pilot low-carbon city policy should continue to be improved, and its role in promoting innovation should be further exploited, so as to fundamentally promote energy saving and carbon reduction. Second, local governments in the pilot regions should tailor their policies to local conditions and classify them within the framework of the pilot policy. Depending on the pollution status of local corporations and the difficulties in carrying out innovative activities, they should both support corporations willing to improve their technologies to reduce pollution and carbon emissions, especially non-state corporations and small corporations, such as providing financial support, subsidies and tax incentives, and impose strict penalties on polluting corporations that refuse to rectify and raise the cost of pollution in order to force them to make

technological changes to reduce pollution and carbon emissions. Finally, corporations should actively assume social responsibility, strictly implement environmental information disclosure, and form a positive interaction with the market.

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