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Hao, Miao and Lyv, Kangjuan and Li, Shiyuan and Hu, Wuyang

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Miao Hao[a], Kangjuan Lyu, Shiyuan Li[a]*

a, SILC Business School, Shanghai University, 20 Chengzhong Rd. Jiading District, 201800 Shanghai, P.R. China.

Authors' contact details:

Miao Hao
Email: Haomiao@shu.edu.cn
Kangjuan Lyu
Email: lvkangjuan@shu.edu.cn
Shiyuan Li
Email: lishiyuan1010@163.com

*Corresponding author

Shiyuan Li
E-mail: lishiyuan1010@163.com
Address: SILC Business School, Shanghai University, 20 Chengzhong RD. Jiading District, 201800 Shanghai, P.R. China.

author's institutional affiliations

SILC Business School, Shanghai University

CRediT authorship contribution state:

Miao Hao: Conceptualization, Methodology, Writing, Review & Editing.
Kangjuan Lyu: Supervision, Project administration, Funding acquisition.
Shiyuan Li: Software, Formal analysis, Data Curation, Visualization.

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Abstract: Environmental regulation is an effective tool for the government to regulate the relationship between ecological civilization and economic development. In this paper, the corporate life cycle theory is incorporated into the environmental regulation policy evaluation, and the impact of environmental regulation on the innovation output of China's enterprises in different development stages is analyzed. The results show that environmental regulation significantly promotes the innovation and green innovation of all enterprises in China, especially for those in the start-up and growing stage, and the impetus for innovation of private enterprises is significantly greater than that of state-owned enterprises. The mechanism behind these results is also analyzed. This paper provides a more abundant theoretical framework and empirical reference for future environmental policy research.

Keywords: Two Control Zones; Innovation; Corporate Life Cycle; Environmental Regulation; Difference-in-Difference.

1. Introduction

The environmental problems China is facing are becoming more and more serious with the rapid development of economy. Due to the high externality of environmental pollution and treatment, it is difficult to solve complex environmental problems only by relying on the market mechanism. government guidance and policy pressure have a significant impact on enterprises' environmental behavior. Therefore, the government must introduce relevant policies to make up for the deficiencies of the market mechanism and promote the transformation of the economy to green and low-carbon. At present, China is at a critical stage of economic transformation, where downward pressure on the economy coexists with pressure on the environment and resources. Faced with the dual pressures, China is constantly exploring a new path of harmonious development between economy and environment. According to *the Bulletin on the State of China's Ecology and Environment* released in June 2020, Of the 337 prefecture-level cities in China, 157 cities reached the air quality standard, accounting for 46.6 percent of the total. Ambient air quality exceeded the standard in 180 cities, accounting for 53.4 percent. Environmental problems still need to be improved. China made an important contribution to the Paris Agreement at the 21st Conference of the Parties to the United Nations Convention on Climate Change (COP21) in 2015, stating explicitly that China's carbon dioxide emissions would peak in 2030 and gradually decline after that. During the general debate of the 75th session of the United Nations General Assembly on September 22, it was mentioned that efforts should be made to be "carbon neutral" by 2060. In 1998, the State Council issued the Plan for the Acid Rain Control Zone and Sulfur Dioxide Pollution Control Zone Division (hereinafter referred to as the "two control zones" policy). The "two control zones" policy is a typical case of China's environmental regulation. By dividing acid rain control zones and sulfur dioxide pollution control zones, China has implemented differentiated pollution regulations and territorial management for the first time.

Kneese and Schultze (1975) believe that in the long term, an important criterion for the effectiveness of environmental regulation policies is whether the regulation promotes the

development of environmental protection technologies. Therefore, effective environmental regulation can not only control pollution emissions and protect the environment, but also stimulate technological innovation as much as possible to obtain the innovation compensation effect of environmental regulation, promote the profit increase of regulated enterprises, and improve the optimization of industrial structure and economic growth of regulated regions. It can be seen that the environmental and economic effects of environmental regulation need to be mediated by technological innovation, which is the key to achieve a "win-win" situation between economic growth and environmental protection. Countries pay great attention to the impact of environmental regulations on technological innovation when they formulate environmental regulations for pollution control, hoping that environmental regulations can stimulate enterprises' technological innovation. There are many ways for environmental regulation to influence enterprise innovation, and the influence effect is not clearly defined. In this case, it is of great significance for promoting economic development and ecological civilization construction to clarify the influence mechanism of environmental regulation on enterprise innovation at the level of enterprise heterogeneity and to dig into the innovation effect of environmental regulation. Enterprises with different life cycles have different R&D plans and innovation intentions. Correspondingly, environmental regulations have different effects on enterprises' innovation at different stages. So, we should analyze the incentive effect of environmental regulation on the technological innovation of enterprises in each life cycle stage, and put forward corresponding policy suggestions. It is of certain practical significance for the government to formulate environmental policies according to the development tasks of different stages and the nature of different enterprises in the future, so as to achieve the social and economic goals effectively.

Hence this paper is organized as follows. In the next two sections, the environmental regulation policy and existing research on related topics are summarized and discussed. In section 4, the hypothesis is obtained through theoretical analysis. Section 5 is sample description and experimental design. Empirical results analysis is shown in section 6, and finally the discussion conclusion.

2. Two Control Zone Policy review

The high growth and high consumption mode of the economy have brought heavy environmental pressure, and environmental pollution also hinders the healthy development of the economy, with industrial emissions dominating pollution (Vennemo et al., 2009). After the promulgation of the *Atmospheric Pollution Prevention and Control Law of the People's Republic of China* in 1987, the Chinese government paid more and more attention to the control of sulfur dioxide emissions, and after the regulations on the division of acid rain control zones and sulfur dioxide control zones were made in the *Atmospheric Pollution Prevention and Control Law of the People's Republic of China* as amended in 1995, the division of the two control zones began at the end of the year. In 1998, the State Council issued the "Acid Rain Control Zone and Sulfur Dioxide Pollution Control Zone Division Program", in the same year, the Ministry of Environmental Protection held a working meeting of the two control zones, after the meeting, 175 regulated cities formulated sulfur dioxide pollution prevention and control plans with the former State Coal Industry Bureau and the State Electric Power Corporation respectively. In 2001, the Ministry of Environmental Protection issued *The "Fifth Five-Year Plan" For The Prevention And Control Of Acid Rain And Sulfur Dioxide Pollution In Two Control Zones*, which sets out the goal for acid rain control and the limit target of

the total emission of sulfur dioxide, it also includes a political and economic system for a series of comprehensive measures to control sulfur dioxide and acid rain, such as reducing the sulfur content of the fuel and improving desulfurization equipment. At the same time, the government has set targets for urban environmental control in the two control zones for the short term (by 2000) and long-term (by 2010).

Since its promulgation in 1998, the policy of two control zones has covered 175 cities in 27 provinces throughout China (as shown in Figure 1). Due to the difference in the principle of pollution formation, the policies of the two control zones are heterogeneous and dynamic, the formation of acid rain is the result of the long-distance diffusion of sulfur dioxide, it's necessary to reduce the growth of sulfur dioxide emissions throughout the region, therefore, the acid rain control area is dominated by regionalized total control (Chai and Duan, 2002).

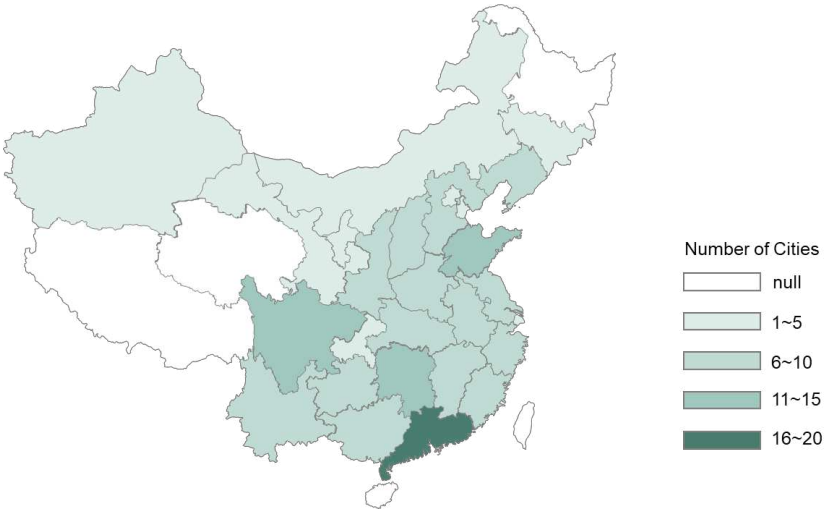

Figure 1. Distribution of Two Control Zones Cities in Each Province

After the implementation of the two-control zone policy, the proper implementation of pollution control measures coupled with the optimization of economic structure, air quality improvement has begun to bear fruit. In 2000, the sulfur dioxide emissions of two control zones cities decreased compared to 1995, 102 cities' sulfur dioxide concentration reached the national secondary standards, and the acid rain deterioration trend has been alleviated.

3. Literature review

What is the impact of command-based environmental regulation on regional development? There are many positive and negative views on this proposition, but most scholars are positive about the lack of consensus on the role of environmental regulation in enterprise innovation, and they generally believe that the implementation of the two control zone policy has improved the quality of the local environment, reduced infant mortality (Tanaka, 2015), raised the average wage of urban workers in acid rain control areas, and triggered the movement of labor from larger cities to smaller cities (Sun, Yang, Ni and Kim, 2019), also significantly promoted the transformation of the city's industrial structure from secondary industry to service industry (Gao, Wang, Zhang and Zong, 2019), and can improve the product by improving the transformation behavior of enterprise products. Quality (Han and Sang, 2018), but at the same time, stricter environmental regulations have also reduced foreign direct investment (Cai, Lu, Wu and Yu, 2016) and inhibited economic growth within

the region (Tang and Liang, 2012), and the policy hinders the productivity growth of enterprises in the region by raising production costs (Sheng and Zhang, 2019).

The research on the impact of environmental regulation on enterprise innovation has been controversial since the Porter hypothesis was put forward. One view is that environmental regulation inhibits innovation, and that environmental regulations cause companies to lose their market share (Jenkins, 1998), and the contemporaneous impact on productivity was negative, as the additional costs of environmental regulation in the short term exceeded the positive impact of the lag period (Lanoie et al., 2008). In particular, for integrated plants, environmental regulation tended to shift investment from production to emissions reductions, resulting in more significant emission reduction costs and low productivity (Gray and Shadbegian, 2003). In addition, enterprises upstream of the production chain generate relatively higher environmental externality and social costs than the value of their production activities (Clift and Wright, 2000). This is also evidenced by empirical research that the Acid Rain Program (ARP) of the United States in 1990 reduced total factor productivity of coal-fired boilers by 1 to 2.5 percent and lost output by between 1 and 6 percent (Hancevic, 2016). Tighter environmental regulations have led to a 2.6 percentage point decline in total factor productivity, with ozone control particularly negatively affecting productivity (Greenstone et al., 2012). In developing countries such as India, command environmental regulation has improved environmental quality, but has had little impact on productivity (Harrison et al., 2015). The second view is that environmental regulation promotes innovation. Porter hypothesis holds that technological innovation in enterprises brought about by environmental regulation can offset additional costs and thus enhance the competitiveness of enterprises (Lanjouw and Mody, 1996; Porter, 1991; Popp, 2010), the most classic example is that Germany and Japan have stricter environmental regulations and faster economic growth than the United States (Porter and Vender, 1995). Strict environmental regulations may encourage industrial innovation mainly because technological advances reduce the cost of pollution reduction (Popp et al., 2010). There is a positive correlation between the implementation of environmental regulations and successful applications for environmental-related patents (Brunnermeier and Cohen, 2003). The degree of strictness of environmental regulation is significantly positively related to the likely development of the investment environment (Arimura et al., 2007). Empirical cases show that the implementation of controls on SO_2 in the United States and NO_X in Germany and Japan was followed by stricter environmental regulations for the corresponding domestic patent applications for technological innovation (Popp, 2006), which also driven companies to adopt higher-level technologies (Popp, 2010) and bring about the decline of labor (Liu, M., Tan, R., and Zhang, B., 2021). Although the "pollution paradise" hypothesis suggests that companies facing environmental regulations are more likely to avoid rather than innovate, Milani (2017) examined R&D data from 21 industrial sectors in 28 countries from 2000 to 2007 and found that more innovation in more permanent industries is needed for mobile-friendly industries, suggesting that innovation can replace migration and become the best way for companies to hedge pollution costs.

Most of the research on China holds a positive view of the Porter hypothesis, arguing that innovation brought about by environmental regulation can offset the increase in costs (Chen, Z., Zhang, X., and Chen, F., 2021) and that its promotion of innovation can also be achieved indirectly through the level of human capital, enterprise size and FDI (Jiang, Wang and Bai, 2013). The research on the specific mechanism of environmental regulation on enterprise innovation focuses on the following levels. First of all, the impact of environmental regulation on enterprise innovation

has a threshold effect, GDP bears the double threshold effect of it (Shen and Liu, 2012), and only in areas with high levels of human capital, environmental regulation will be positive to promote technological innovation (Du, K., Cheng, Y., and Yao, X., 2021), and the threshold effect also exists in different threshold conditions and different value chain stages (Song, Li and Han, 2014). Secondly, regional heterogeneity exists in the effect of environmental regulation on enterprise innovation, for enterprise innovation in more developed areas of the economy, environmental regulation has a positive impact, while backward areas show a certain negative or uncertain impact (Zhang, Y.J., and Wang, W., 2021), Similarly, regions with stronger awareness of property rights and environmental protection have a more significant positive promotion effect (Jiang, 2015). Thirdly, the effects of different types of environmental regulation are also different, according to classification principles, there are roughly the following views: cost-based regulation is "crowding out effect", investment-based regulation is "incentive effect" (Zhang, Zhang and Cai, 2016), the incentive effect of command-based regulation is not significant, while the incentive effect of voluntary-based regulation is more significant (Ma, Guo and Cha, 2011; Xu, Zhao and Hong, 2013). However, some scholars believe that command-based regulation with laws and regulations or administrative orders as the carrier is more effective (Guo, 2019). Finally, the effect of environmental regulation on enterprise innovation also shows the heterogeneity of the industry, scholars generally believe that the promotion of enterprise innovation in high-polluting industries is more significant (Yu, Wang and Liu, 2014; Jiang, 2015), and heavy pollution industry needs environmental regulations The system is more intense (Du and Li, 2016), but some scholars believe that the promotion of industries with higher technology intensity, low pollution, and high investment in R&D is more significant (Li, Han and Song, 2013).

Through the analysis of the previous literature, it can be found that most of the studies remain to measure the heterogeneity of environmental regulation on the cross-section level of enterprises, and lack of attention to the differences in time dimensions, that is, the corporate life cycle. Adizes (1988) suggests that enterprises at different stages of the life cycle have a different difficulty of change adjustment and self-control stability, and their willingness to innovate is also different, so we predict that environmental regulation will have different effects on the innovation of enterprises at different stages of the life cycle.

The main contribution of this study is reflected in the following aspects: 1) This paper will discuss from the perspective of corporate life cycle theory, evaluate the feedback of enterprise innovation on environmental regulation in different periods, and expand the depth and breadth of environmental regulation policy research. 2) The two control zones policy is taken as a quasi-natural experiment, using Difference-in-Difference model. This paper will also conduct a series of robustness tests to improve the credibility and explanatory power of the conclusions. 3) This paper will judge the heterogeneity of the impact of environmental regulation on the innovation of enterprises with different ownerships under the current national conditions of China, and discuss the causes behind it. In summary, this paper will not only provide a comprehensive and reasonable explanation for the debate on the effect of environmental regulation on enterprise innovation, but also provide a theoretical reference for how to formulate environmental regulation policy more scientifically.

4. Theoretical analysis and hypothesis

There are many rules about the division of life cycle, but this study mainly uses the division rules of Adizes (1988) to divide the enterprise into four stages: start-up, growth, maturity and recession. Combining the innovative characteristics of each stage, we analyze and assume the following for businesses of different life cycle stages:

Start-up companies has not yet formed stable financial revenues and expenditures, and its technical foundation is very weak. For startups without core technology patents, most of them are in the imitation and exploration stage. Entrepreneurs are in urgent need of talent and capital, and at this time, enterprises are faced with internal and external uncertainties: internal one is the uncertainty of the R&D success rate, external one is the uncertainty of whether the market demand matches with the product positioning (Li, Zhou and Wang, 2009). Therefore, enterprises' R&D intention and capability are relatively low, the conversion rate of innovation achievements is also low, so the commercial value cannot be reflected. The credit supply department has a low willingness to lend to such enterprises. Lack of external funding support, it is difficult for companies to meet the high capital demand of R&D only by relying on self-owned funds. In addition, the product development direction of enterprises in this stage is not stable (Chen, 1995). However, the listed enterprises should have a stable product positioning, and the listing also brings a powerful source of funds for them. The above problems can be well solved. Moreover, start-ups need to establish corporate image through innovation so as to attract more investment. Therefore, we believe that companies in the start-up stage will make use of the policy of environmental regulation to carry out high-quality innovation, but they may not be able to carry out large-scale innovation due to the limitation of their own factor endowment.

Hypothesis 1: Environmental regulations have a certain role in promoting innovation with start-up enterprises

From the perspective of enterprise strategy, the growing enterprises have just gained a foothold in the market and the main goal is to expand market share, enterprises pay attention to diversified development and strive to broaden their product lines. Therefore, enterprises tend to invest more capital in R&D projects with intangible assets. The main task at this stage is to build a pioneer advantage to rival potential competitors (Jovanovic, 1982). Besides, companies face more differentiated market requirements as they age (Miller and Friesen,1985). Enterprises in the growth stage have strong technological innovation ability and can quickly put innovation into use (Chen, 1995), innovation is the main source of its competitiveness to gain market share (Feng and Wei, 2003). From the perspective of R&D intention, the orientation of enterprises in the growth period will shift from simply seeking survival to development and striving for resources from all sides. With the increasing complexity of markets and consumers faced by enterprises, in order to win a stable customer base more quickly, the proportion of R&D investment related to products will also be relatively high in corporate expenditures. Firms in the growth stage are sensitive to incentives related to innovation and have some capital available to offset rising production costs.

Hypothesis 2: Environmental regulation contributes relatively much to the innovation of growing enterprises.

Enterprises in the mature stage have established a relatively perfect sales network, their commercial value has been very clear, and they have also obtained a very stable market reputation. Therefore, they have a higher degree of trust in credit funds, and they can get higher financing at a lower cost (Huang, 2016). The amount of external capital held by some enterprises can exceed their own capital. At this time, capital is no longer the biggest problem for enterprise innovation, but

whether they can break the routine to create new innovative behaviors has become the biggest problem faced by enterprises. From the point of the risk, willingness and ability of innovation, the market and consumer portraits faced by enterprises have been basically fixed, So the management fees spent on expanding market share and the purchase of fixed assets have fallen sharply, and the long-term homogeneous accumulation of knowledge and human capital of enterprises leads to path dependence, so the innovation mode is basically gradual innovation along the established track (Li, Zhou and Wang, 2009). After the market exploration in the early stage, the accumulation of research and development experience and the support of the feedback information of the sales network, the enterprises R&D is often "targeted", and the risk of research and development failure is greatly reduced (Tong et al., 2018). In addition, mature enterprises tend to choose R&D projects with large capital investment, strong uncertainty, long return cycles but large future benefits (e.g., research and development of invention patents), which are generally more environmentally friendly and environmentally sensitive.

Hypothesis 3: Environmental regulation is relatively effective in promoting innovation in mature enterprises.

Due to the rigid system, backward technology, financing difficulties and other problems, enterprises in the recession period are prone to the problems of brain drain and capital chain fracture. At this stage, market share, profits and sales revenues all declined. In the recession period, there are often problems in the internal structure of enterprises, such as management discharge, redundancy, and lack of innovation consciousness (Li et al.,2011), which may make companies conservative. Most of the older companies are making process innovations rather than product innovations, which means that the scope and breakthrough of innovation have dropped dramatically (Kueng et al., 2014). At this stage, the enterprise's expenditure structure has become rigid, the new innovation expenditure approval process is complex, and the enterprise will not have extra funds to carry out long-cycle, high-investment and high-risk innovation behaviors. Coupled with the old production equipment of enterprises, serious brain drains and other problems, the risk appetite of enterprises has fallen to the bottom, innovation will and innovation ability have been greatly challenged. Therefore, enterprises at this stage prefer to hedge costs by adopting circumvention measures rather than technological innovation in the face of environmental regulation.

Hypothesis 4: Environmental regulation has a relatively small effect on the promotion of innovation for enterprises in the recession period.

The above analysis on the time dimension of innovation characteristics at the life cycle level of the firm can reveal the stage heterogeneity of innovation, and the analysis on the cross-section level of the firm is also necessary.

From the perspective of ownership attributes, state-owned enterprises are the most rapid in responding to policies and also the leaders in fulfilling political obligations. However, from the perspective of innovation, the innovation performance of state-owned enterprises is not sensitive to policy incentives due to the complexity of management levels and the diversity of business objectives (Wei et al., 2017). In contrast, among non-state-owned enterprises, foreign-funded enterprises have diversified sources of capital. The R&D institutions of foreign-funded enterprises in China generally have strong technical and financial strength, and can absorb a large number of outstanding talent resources. However, due to the existence of home country holding, the weight of policy considerations for the host country will be reduced, that is to say, the decision-making participation of the parent company will have a loss on the innovation efficiency of foreign-funded

enterprises (Francesco, 2012). Private enterprises face the fiercest market competition, in order to survive in the industry and quickly occupy their own place, private enterprises will be more inclined to increase innovation expenditure to shape the unique core competitive advantage of the enterprises, Therefore, environmental regulation has the strongest effect on innovation of private enterprises, followed by foreign-funded enterprises and state-owned enterprises.

Hypothesis 5: For enterprises of different ownership at different life cycle stages, the effect of environmental regulation on their innovation is also different.

5. Data description and empirical design

Based on the above background, we choose two control zones policy as an exogenous shock, to construct a Quasi-natural experiment, and we select the data of listed companies and cities from 1995 to 2015. The data used in this study came from *China City Statistical Yearbook* and information disclosure data of listed companies in CSMAR. Table 1 shows the distribution of the samples.

Table 1. Number of Two Control Zones Cities in Each Province

Pilot Province	Number of cities	Pilot Province	Number of cities
Anhui	6	Liaoning	9
Beijing	1	Neimenggu	5
Fujian	6	Ningxia	2
Gansu	4	Shandong	12
Guangdong	17	Shanxi	7
Guangxi	8	Shaanxi	6
Guizhou	6	Shanghai	1
Hebei	8	Sichuan	13
Henan	6	Tianjin	1
Hubei	8	Xinjiang	1
Hunan	12	Yunnan	6
Jilin	4	Zhejiang	9
Jiangsu	9	Chongqing	1
Jiangxi	7	**Total**	**175**

This paper takes polluting industry enterprises in Shanghai and Shenzhen stock market A-shares from 1995 to 2015 as research samples. Firstly, determine polluting industry and non-polluting industry. Polluting industries involve 21 industries, such as mining and manufacturing, as shown in the table. Second, identify polluting enterprises. Third, eliminate continuous loss-making enterprises to maintain the stability and validity of the sample. The treatment group in this experiment is the cities in the pilot area of "two control zones", including a total of 175 cities.

Table 2. Descriptive statistics of major variables

	N	Mean	Std. Dev.	min	max
ln(patent+1)	25631	.511	1.022	0	8.173
ln(greenpatent+1)	25631	.138	.506	0	6.771
DD	25631	.736	.441	0	1
ln(asset+1)	25631	21.759	1.471	0	28.194
age	25631	13.796	7.055	0	41
FG	24293	2.455	354.236	-21756.816	24467.525

ROA	25628	.051	4.825	-51.298	758.738
Liquidity	25541	1.755	2.608	-5.132	204.742
ln(NL+1)	17753	2.393	.969	0	4.06

Table 3. Descriptive statistics by life cycle stages

	Start-up	Growing	Mature	Recession
Observations	2,797	7,392	12,266	2,639
ln(patent+1)	.512	.497	.5	.577
ln(greenpatent+1)	.125	.138	.131	.179
DD	.783	.72	.734	.755
ln(asset+1)	21.691	21.776	21.801	21.647
age	13.943	13.495	13.88	14.164
FG	7.83	-1.586	4.844	-3.109
ROA	.003	.118	.028	.027
Liquidity	1.772	1.762	1.743	1.789
ln(NL+1)	2.342	2.361	2.409	2.48

Treatment variable

Two Control Zones (DD). The first year of policy implementation was 1998. it was a dummy variable. which takes a value 1 if a firm belongs to the two control zones city.

Dependent Variable

Innovation (I) Patent is a reasonable index to measure the innovation performance at the enterprise level (Hagedoorn and Cloodt, 2003). The value of patent lies in limiting business competition and improving profitability. Compared with other innovation indicators, patent has stronger objectivity. So, we measure technological innovation using the number of new patent applications and number of invention patents filed by the company each year.

Corporate life cycle

The methods used to classify enterprise life cycle can be summarized into the following three categories: univariate method (such as enterprise age, size, profit index, etc.), comprehensive index (Anthony and Ramesh, 1992) and cash flow model (Dickinson, 2011). The univariate method is too simple to fully judge the complex enterprise individual. The premise of the comprehensive index method assumes that there is a linear relationship between operating cash flow, sales revenue, listing years and accounting surplus, which has some defects. Cash flow model method reflects the characteristics of operating risk, profitability and growth rate in different life cycles through the positive and negative combination of the net cash flows of three kinds of activities, such as operation, investment and financing, It can not only avoid the interference of inherent industry differences, but also avoid the subjective assumption on the sample distribution of the life cycle, which has a strong operability and objectivity (Chen, 2008; Cao, 2010; Huang et al., 2016). As shown in Table 4, we used the cash flow model to determine the enterprise life cycle and divides the samples into four stages: the start-up, growing, maturity and recession stage. company has three types of net cash flow activities (operating, investing and financing), each of which has a sign. The cash flow pattern sign for each life cycle phase is shown below.

Table 4. The characteristics of cash flow in different corporate life cycle stages

	Start-up	Growing	Mature				Recession	
	Introduction	Growing	Mature	Shake-out	Shake-out	Shake-out	Decline	Decline

Cash flows from operating activities	−	+	+	−	+	+	−	−
Cash flows from investing activities	−	−	−	−	+	+	+	+
Cash flows from financing activities	+	+	−	−	+	−	+	−

Control variables

in order to ensure the accuracy of the research, reduce the omitted variable bias, improve the efficiency of regression estimate, we selected the following control variables:

Firm Size (FS) Larger companies are generally more innovative and tend to file more patents (Hall and Ziedonis, 2001)。We use the logarithm of total assets to represent the size of the company (Chang et al., 2015).

Firm Age (FA) With the increase of the age of the firm, the inertia of the organization will reduce the innovation willingness of the firm (Guan and Yam, 2015).

Firm Growth (FG) The higher the growth of the firm, the lower the elasticity of daily expenditure, and the more the capital input of R&D activities accordingly. The calculation formula is: (current operating income - Operating income of last year)/ Operating income of last year.

Return on Total Assets (ROA) Measured by net profit/total assets, it reflects the value creation ability of the enterprise.

Liquidity Ratios (Liquidity) Measured by current assets/current liabilities, and it reflects the short-term liquidity capacity of an enterprise.

Economic status (NL). We use DMSP night light data to represent the economic status of the city (Henderson, Storeygard and Weil, 2012; Chen and Nordhaus, 2011).

Based on the above design, we construct the DID model as follows:

$$\mathrm{I}_{ijt} = \alpha_0 + \alpha_1 DD_{jt} + \lambda X_{ijt} + \gamma_i + \nu_t + \varepsilon_{ijt}$$

The subscript i indicate the enterprise and t indicate the year. Interaction term coefficient α_1 is the standard coefficient of DID model, if it is significantly positive, we can infer that the two control zone policy is effective for innovation. X_{ijt} is a series of control variables. The city and time factors were controlled for the model. ε_{ijt} is the error term.

6. Empirical results

6.1 Full sample baseline regression

As shown in table 5, we select all listed companies as research samples to test the impact of the two control zone policy on enterprise innovation and green innovation. Here we use the number of patents and green patent grants to instrument innovation and green innovation respectively. Columns 1 and 3 are results with no control variables added, to reduce the bias caused by missing variables, columns 2 and 4 show the empirical results after adding control variables. Then we choose listed enterprises that emit sulfur dioxide as samples for research. The structure is the same as Table 5, and the results are shown in Table 6.

Table 5. The innovative impacts on full sample enterprises

	(1)	(2)	(3)	(4)
	Patent	Patent	Green patent	Green patent
DD	0.1638***	0.1835***	0.0486*	0.0517***
	(0.0500)	(0.0292)	(0.0279)	(0.0148)
ln (asset+1)		0.1700***		0.0765***
		(0.0192)		(0.0154)
age		-0.0173***		-0.0075***
		(0.0040)		(0.0025)
FG		-0.0000		-0.0000
		(0.0000)		(0.0000)
ROA		0.0013***		0.0006***
		(0.0002)		(0.0002)
Liquidity		0.0014		-0.0010
		(0.0028)		(0.0010)
ln (NL+1)		-0.2090*		-0.1436***
		(0.1140)		(0.0519)
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
_cons	-0.3118	-3.4975	-0.1048	-1.4809
	(0.0184)	(0.3827)	(0.0129)	(0.3066)
N	25,631	16,513	25,631	16,513
R-squared	0.277	0.282	0.128	0.150

Note: standard errors are in parentheses; *p<0.1，**p<0.05，***p<0.01.

Table 6. The innovative impacts on SO_2 emission enterprises

	(1)	(2)	(3)	(4)
	Patent	Patent	Green patent	Green patent
DD	0.2323***	0.2708***	0.0714**	0.0669***
	(0.0603)	(0.0463)	(0.0345)	(0.0214)
ln(asset+1)		0.2041***		0.0986***
		(0.0283)		(0.0205)
age		-0.0116**		-0.0072**
		(0.0050)		(0.0033)
FG		-0.0000		-0.0000
		(0.0000)		(0.0000)
ROA		-0.0047		-0.0003
		(0.0036)		(0.0038)
Liquidity		0.0030		-0.0006
		(0.0039)		(0.0011)
ln(NL+1)		-0.3812*		-0.2237***
		(0.1933)		(0.0765)
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
_cons	-0.5908	-4.3012	-0.1372	-1.9041

	(0.0351)	(0.5576)	(0.0187)	(0.3977)
N	18,919	12,019	18,919	12,019
R-squared	0.333	0.347	0.152	0.182

Note: standard errors are in parentheses; *p<0.1，**p<0.05，***p<0.01.

In general, both the innovation and green innovation of polluting enterprises have been significantly positively affected after the implementation of the two control zones policy. Moreover, this environmental regulation has a stronger promoting effect on the innovation of polluting enterprises, but on the whole, the policy has a weaker driving force on green innovation.

From the aspect of enterprise internal control variables, the Firm Size plays a significant role in promoting innovation and green innovation, but Firm Age has a significant negative impact on innovation and green innovation. This suggests that larger firms have enough capital to support research and development activities and are motivated to apply for patents. However, with the growth of firm age, the innovation consciousness of enterprises gradually weakens. The relatively stable market share and increasingly fixed corporate image make enterprises lose willingness to carry out breakthrough innovation behaviors, they are also reluctant to put money into research and development activities with long payback periods and high investment.

From the perspective of the external environment control variables, the more prosperous the regional economy is, the more restrained the innovation of enterprises will be, but the inhibition effect on green innovation is significantly lower than that on total innovation, which indicates that the environmental protection awareness of enterprises in developed regions is relatively strong

6.2 Subsample regression of corporate life cycle

For the heterogeneity research of regulated polluting enterprises, we divided this sample into four life cycle stages according to the cash flow model mentioned above, and constructed four sub-samples for empirical results as shown below.

Table 7. The life cycle heterogenous innovative impacts on SO2 emission enterprises

	(1) Start-up	(2) Growing	(3) Mature	(4) Recession
DD	0.2154**	0.3326***	0.1573***	0.2854*
	(0.1035)	(0.0859)	(0.0561)	(0.1551)
Control variables	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
_cons	-0.4420	-2.3941	-3.5568	-8.2945
	(1.7426)	(1.1765)	(0.9904)	(3.2737)
N	1,315	3,515	5,701	1,273
R-squared	0.517	0.378	0.376	0.545

Note: standard errors are in parentheses; *p<0.1，**p<0.05，***p<0.01.

Table 8. The life cycle heterogenous green innovative impacts on SO2 emission enterprises

	(1) Start-up	(2) Growing	(3) Mature	(4) Recession
DD	0.0961**	0.0591*	0.0291	0.0541
	(0.0398)	(0.0325)	(0.0252)	(0.1010)
Control variables	Yes	Yes	Yes	Yes

City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
_cons	0.7137	-0.2283	-1.3106	-6.0703
	(0.6215)	(0.5688)	(0.3772)	(3.4539)
N	1,315	3,515	5,701	1,273
R-squared	0.344	0.197	0.202	0.447

Note: standard errors are in parentheses; *p<0.1，**p<0.05，***p<0.01.

From the perspective of total innovation, the two control zones policy has a significant promoting effect on enterprise innovation at all life cycle stages, especially for enterprises in the growing stage, followed by the recession stage and the start-up stage, and the last is the mature stage. This is partly different from the hypothesis in the section 4. The result of growing enterprise consistent with the hypothesis of above, but the situation of mature and recession companies is contrary to the hypothesis. We can infer that this is because the mature period is the stable period in the life cycle of the enterprise, the research and development activities of enterprises in this stage are generally "targeted", and there is no need to follow the policy tendency and carry out abnormal R&D plans, and the mature risk coping mechanism of enterprises also makes environmental regulations have little impact on their core business. Therefore, although the innovation behavior of enterprises in the mature stage will increase after environmental regulation, the growth power is inevitably less than that of enterprises in other stages. On the contrary, enterprises in the recession period are in the stage of self-help after experiencing the period of shake-out. At this time, enterprises have lost the stable core competitiveness and market share, so it is a strategic necessity for enterprises to follow the policy guidance to innovate. However, enterprises will not consider carrying out green innovation with high investment and high quality in recession period, as shown in Table 8, so it can be inferred that the initiative of enterprises in the recession period to apply for patents does not come from the growth of innovation ability, but is only a temporary measure in the face of regulatory policies.

As to the green innovation, two control zones policy has a significant promoting effect on both start-up and growing enterprises, among which the start-up enterprises have the best performance, which is consistent with the above hypothesis. Enterprises in the start-up and mature stage have great motivation to improve their corporate image, so as to attract more investment. Therefore, it is undoubtedly a good choice to apply for environmentally friendly patent during the implementation period of environmental regulation. By comparison with Table 7, it can be seen that although the growth strength of start-ups overall innovation output is weak, they are more willing to carry out green innovation, which is the fresh troops of green innovation in this environmental regulation.

6.3 Enterprise ownership heterogeneity regression

In order to explore the potential impact heterogeneity of the environmental regulations on enterprise's green innovation of different ownership, to test the impact of environmental regulations on the environmental awareness of different enterprises. We divide the samples into state-owned enterprises (SOEs) and private enterprises according to the actual controller attributes, and investigate how the two types of enterprises in different life cycles respond. Table 9 presents the empirical results.

Table 9. The ownership heterogenous green innovative impacts on SO2 emission enterprises

Panel A: SOEs	(1)	(2)	(3)	(4)	(5)

	Full sample	Start-up	Growing	Mature	Recession
DD	0.0290	1.1035**	0.0353	0.0140	0.0425
	(0.0305)	(0.5054)	(0.0513)	(0.0369)	(0.1180)
Control variables	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
_cons	-2.4479	-0.4957	-0.3489	-1.2824	-6.2025
	(0.6162)	(1.1414)	(0.6566)	(0.6057)	(4.6549)
N	7,645	690	2,220	3,732	901
R-squared	0.213	0.254	0.291	0.254	0.504

Panel B: Private Enterprise	(1) Full sample	(2) Start-up	(3) Growing	(4) Mature	(5) Recession
DD	0.1118***	0.1008*	0.0809**	0.0291**	-1.5615***
	(0.0423)	(0.0496)	(0.0329)	(0.0121)	(0.2198)
Control variables	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
_cons	-1.4617	-0.0850	-0.9177	-0.5010	-1.3537
	(0.6120)	(0.6440)	(0.3697)	(0.5732)	(0.6829)
N	3,607	548	1,073	1,598	293
R-squared	0.228	0.647	0.251	0.200	0.476

Note: standard errors are in parentheses; *p<0.1，**p<0.05，***p<0.01.

According to the result we found that two control zones policy significantly improve the green innovation output of private enterprises, but had a weak impact on state-owned enterprises. After the differentiation of life cycle stages, it can be seen that the incentive effect of environmental regulation on green innovation is mainly reflected in private enterprises in the start-up, growing and maturity stages, while it has a significant negative effect on private enterprises in the recession stage. The results were consistent with the original hypothesis. To a certain extent, it also accords with China's national conditions. State-owned enterprises undertake the social responsibility of creating jobs and providing quasi-public goods, which occupy the R&D funds of enterprises to some extent (Liu, Lin and Leng, 2020). The executives of state-owned enterprises are usually more conservative and not keen on high-cost and high-risk green innovation. Besides, State-owned enterprises are usually in the upper stream of higher profits and have less incentive to innovate. In contrast, private enterprises, faced with more fierce market competition, are motivated to shape their unique social image compared with other enterprises through more socially responsible innovation. Especially for enterprises that are in a period of rapid growth, their technology changes are faster and the management level is flatter, which makes it easier to make environmentally friendly innovation decisions. It is worth noting that environmental regulation has a significant inhibiting effect on the green innovation of private enterprises in the recession period. Private enterprises are more profit-driven. In the recession period, the daily operating expenses and management expenses of private enterprises account for the majority. The rising pollution control costs brought about by environmental regulations make them more exhausted and unable to afford high-quality green innovation.

7. Robustness test

7.1Parallel trend test

To verify the dependent variable of different cities have parallel trends before treatment, which is one of the basic assumptions of DID. We conduct a parallel trend test. After de-trending and centering the estimates on the year of treatment, Figure 2 plots the estimate coefficients and the 95% confidence intervals.

$$\text{Innovation}_{ijt} = \alpha_0 + \alpha_1 {D^{-2}}_{jt} + \alpha_2 {D^{-1}}_{jt} + \alpha_3 Current_{jt} + \alpha_4 {D^{+1}}_{jt} + \alpha_5 {D^{+2}}_{jt} + \alpha_6 {D^{+3}}_{jt} + X_{ijt} + \varepsilon_{ijt}$$

As shown in Figure 2, the coefficients on the treatment variables are insignificantly different from zero for days before policy announcement year, with no trends in innovation prior to policy intervention. In addition, innovation increases immediately after *current*, such that D^{+1}, D^{+2} and D^{+3} are significantly above 0. To sum up, after controlling other impacting factors, innovation and green innovation improvements do not precede policy announcement.

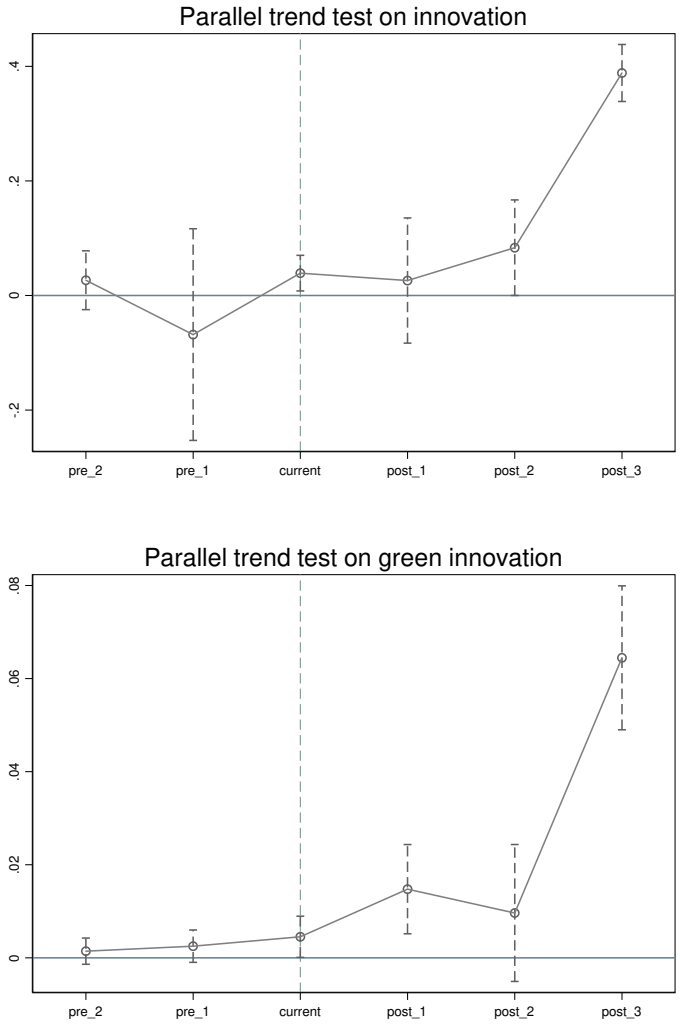

Figure 2. Parallel trend test

7.2 Excluding specific industries

In terms of research topic of this article, the source of endogeneity may be sample selectivity bias caused by cash flow model method. In some sectors there may be a specific mode of cash flow,

which brings an industry together in a single lifecycle phase. As a result, the empirical results are dominated by the characteristics of some industry groups. Referring to Liu et al.'s method, the real estate industry and the comprehensive industry samples were removed, and the regression results remained consistent.

Table 10. The innovative impacts on enterprises

	Full sample				SO_2 enterprises			
	Patent	Patent	Green patent	Green patent	Patent	Patent	Green patent	Green patent
DD	0.1899***	0.2182***	0.0567*	0.0537***	0.2323***	0.2708***	0.0714**	0.0669***
	(0.0543)	(0.0384)	(0.0302)	(0.0181)	(0.0603)	(0.0463)	(0.0345)	(0.0214)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	23315	14885	23315	14885	18919	12019	18919	12019
R-squared	0.297	0.307	0.135	0.160	0.333	0.347	0.152	0.182

Note: standard errors are in parentheses; *p<0.1，**p<0.05，***p<0.01.

Table 11. The lifecycle heterogenous on SO_2 emission enterprises

	Patent				Green patent			
	Start-up	Growing	Mature	Recession	Start-up	Growing	Mature	Recession
DD	0.2154**	0.3326***	0.1573***	0.2854*	0.0961**	0.0591*	0.0291	0.0541
	(0.1035)	(0.0859)	(0.0561)	(0.1551)	(0.0398)	(0.0325)	(0.0252)	(0.1010)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1,315	3,515	5,701	1,273	1,315	3,515	5,701	1,273
R-squared	0.517	0.378	0.376	0.545	0.344	0.197	0.202	0.447

Note: standard errors are in parentheses; *p<0.1，**p<0.05，***p<0.01.

Table 12. The ownership heterogenous green innovative impacts on SO_2 emission enterprises

Panel A: SOEs	(1) Full sample	(2) Start-up	(3) Growing	(4) Mature	(5) Recession
DD	0.0290	1.1035**	0.0353	0.0140	0.0425
	(0.0305)	(0.5054)	(0.0513)	(0.0369)	(0.1180)
Control variables	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
N	7,645	690	2,220	3,732	901
R-squared	0.213	0.254	0.291	0.254	0.504

Panel B:	(1)	(2)	(3)	(4)	(5)

Private Enterprise	Full sample	Start-up	Growing	Mature	Recession
DD	0.1118***	0.1008*	0.0809**	0.0291**	-1.5615***
	(0.0423)	(0.0496)	(0.0329)	(0.0121)	(0.2198)
Control variables	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
N	3,607	548	1,073	1,598	293
R-squared	0.228	0.647	0.251	0.200	0.476

Note: standard errors are in parentheses; *p<0.1，**p<0.05，***p<0.01.

8. Conclusion

The effectiveness of an environmental policy is reflected in its ability to promote innovation and improve economic efficiency while reducing emissions. How to motivate enterprises to carry out high-quality and environment-friendly innovation and realize the transformation of economic growth from "extensive" to "efficient" is an important issue faced by government departments. From the microscopic perspective of corporate life cycle, this study longitudinal analyzes how enterprises in different stages respond to specific environmental regulations. On the whole, both for all enterprises and regulated polluting enterprises, the implementation of environmental regulation has stimulated the increase of the patent grants number, and at the same time improved the quality of innovation, that is, promoted the growth of green innovation. From the perspective of life cycle stages, the incentive effect of environmental regulation on enterprises innovation in the start-up and growing stages is particularly significant, while the positive effect on enterprises in the mature and recession stages is not significant, as for green innovation, it is more concentrated in start-ups. From the perspective of ownership, environmental regulation has a more significant promoting effect on green innovation of private enterprises in the start-up and growing stages, but significantly inhibits green innovation of private enterprises in the recession stage.

This study fills the gap of micro research on environmental regulation on enterprise performance, integrates the corporate life cycle theory into the assessment of environmental policy effectiveness, examines the micro effect of environmental policy from the time dimension, and also adds the heterogeneity analysis of ownership to further open the "black box" of environmental policy research. A series of possible causes of the results are also discussed. It can provide new ideas for future policy research.

Based on the above empirical results, we can draw a conclusion that to solve the environmental pollution problem on the premise of high-quality economic development, we not only need to rely on the adjustment role of market mechanism, but also need to give full play to the regulatory role of policy regulation. The two control zones policy not only makes the regulated areas achieve the emission reduction target within specified period, but also promotes the innovation output of enterprises, and realizes the win-win situation of economic and environmental performance. To meet the task of green, sustainable and high-quality development of economy, this study also provides scientific support for government to highly appreciate the role of command-based environmental regulation in environmental governance.

It is not contradictory to strengthen environmental regulation and improve the quality of economic development. The key is to make good use of flexible and appropriate environmental policies and give continuous innovation incentive to enterprises. We find that the effect of the two

control zones policy is different among enterprises at different life cycle stages and enterprises of different ownership. It also reflects that the command-based environmental regulation cannot give good consideration to fairness while pursuing emission reduction. Therefore, future environmental policy design should consider the heterogeneity between enterprises. First, Companies that are just starting up and growing at a rapid pace should be given more support for innovation, and some incentives should be given for high-quality green innovation. Besides, a relative fair competition environment should be created for private enterprises, and more pressure should be put on state-owned enterprises in the design of supervision mechanism.

Future research can start from the following aspects: First, the key to the establishment of command-type environmental regulation is how to determine the regulated areas so as to ensure that the emission reduction will not be carried out at the cost of the local enterprises' development. It requires a full understanding of the life cycle stages and characteristics of enterprises within the regulated region, so as to make environmental policies more flexibly. Second, we can also study the heterogeneous impacts of other kinds of environmental policies on enterprises in different life cycle stages, so as to build a more comprehensive environmental policy evaluation system.

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