Economic Modelling 89 (2020) 19–31

Contents lists available at ScienceDirect

Economic Modelling

journal homepage: www.journals.elsevier.com/economic-modelling

Regulation and innovation: Examining outcomes in Chinese pollution control policy areas☆

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ARTICLE INFO

JEL codes:
Q52
Q58
O32

Keywords:
Environmental regulations
Innovation
Porter hypothesis
Difference-in-difference-in-differences estimation

ABSTRACT

In this paper, we examine how two regionally implemented environmental initiatives in China have impacted the innovation ability of Chinese-listed firms. The regional implementation of these policies, with non-policy regions serving as controls, offers researchers the perfect conditions for a natural experiment. Using research and development (R&D) expenditures and patents as a proxy for innovativeness, we compare the record of innovation of firms inside the policy zones with firms outside the policy zones. We use a Difference-In-Difference-In-Differences (DIDID) method to eliminate endogeneity and take the quality of the patents into account by incorporating sub-items. Results show only one of the regulations had a positive effect and that low quality patents account for most of the innovation. We conclude that reasonably designed environmental regulations, when implemented regionally in competitive industries, do improve Chinese firms' innovation ability in line with the Porter Hypothesis. The results help us derive some useful policy implications regarding innovation.

1. Introduction

Air pollution in China has become a major topic of concern for both foreign observers and the Chinese government in recent years. "The Air Pollution Prevention and Control in Key Regions Law", enacted in 2012, established a framework for "Air Quality Control Zones" (AQCZ)[1] to be implemented at the regional level. Its predecessor, the "Two Control Zones" plan (TCZ),[2] piloted the idea of regional implementation of pollution control zones in 1998 (Li and Gao, 2002). The direction of recent Chinese regulatory policy is clear: the government hopes firms in China will adopt more environmentally-friendly and efficient production processes, particularly in high-polluting industries. However, new environmental regulations bring a new dilemma: Could these regulations impair the labor-intensive Chinese industries and impede their economic development?

In our paper, by researching two air quality-related environmental policies, we explore how firms in China were influenced by such regulations. Environmentalists and some researchers argue that stringent and well-designed environmental policies provide firms an incentive to develop more advanced and less polluting means of production. In the presence of such regulation, firms are actively discouraged from easier but more negative externality-inducing methods, driving

☆ We thank our editor Professor Sushanta Mallick and guest editor Professor Lutao Ning, and our anonymous referees. We are grateful to the participants of the China Economy Seminar in the Department of Economics at Harvard University, the Economic Modeling Conference on the Challenges of Managing and Modeling Innovation and Growth in China hosted by Renmin University in Beijing, and Productivity Research Network Technical workshop on "Productivity drivers in Asia: the firm level perspective" hosted by the Asian Development Bank Institute in Tokyo, Japan. We are further indebted to Prof. Sushanta Mallick and Lutao Ning, Dr. Dongyang Zhang, as well as our anonymous referees for their helpful remarks on earlier versions of this paper. The usual disclaimer applies.

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[1] The full name of AQCZ is "Twelfth Five-Year Plan on Air Pollution Prevention and Control in Key Regions". The zone covers three key regions (the Beijing-Tianjin-Hebei, the Yangtze River Delta Area, and the Pearl River Delta Area) and 10 metropolitan clusters, involving 19 provincial level jurisdictions and 117 cities in total. Though this zone covers only 14% of the country's total land area, it accounts for nearly half (48%) of the country's population, 71% of the nation's GDP, and 52% of the country's coal consumption CAAC. The AQCZ policy includes provisions to reduce on SO_2 and NOx, and a comprehensive list of air pollution criteria including ozone, PM2.5, and others adopted from international clean air standards.

https://doi.org/10.1016/j.econmod.2019.09.041
Received 20 January 2018; Received in revised form 21 August 2019; Accepted 27 September 2019
Available online 3 October 2019

sustainability-oriented R&D efforts and a long-term increase the competiveness. Thus innovation resulting from environmental regulations can make firms comparatively competitive against foreign competitors. This theory, known as the Porter Hypothesis, has been tested many times in developed countries (Esty and Porter, 1998; Albrizio et al., 2017).

Adding to the history of work on the Porter hypothesis in development economics, our paper delves into the question of whether environmental policies increase firms' innovation and hence benefit them in the long term. The contribution of this paper is to test the real-world applicability of the Porter Hypothesis by examining the effects of two specific environmental policies on affected Chinese firms. We use the Difference-in-Difference-in-Differences (DIDID) method to identify the impacts on firms' innovation ability, which is measured by two indexes: R&D expenditures and the number of patents. We also look into the sub-items of patents to explore the mechanism of how environmental regulations influence innovativeness. Our research method is a comparatively more precise paradigm to test the Porter Hypothesis for the following reasons. First, we consider two specific policies, which is more consistent with the policy requirements put forward by the Porter Hypothesis itself. Compared with previous papers using pollution control expenditures (Jaffe and Palmer, 1997; Berman and Bui, 2001), or timing of the introduction of environmental regulations (Popp, 2006), our paper unprecedentedly compares patenting activities before and after the implementation of environmental policies. Apart from that, we adopt two different types of policies. The TCZ policy is more of a pilot or trial stage policy, which means the government only set a general goal. AQCZ, on the contrary, is a more centralized policy. Additionally, these two policies cover different scopes of pollutants. These conditions provide good quasi-experiments to test how different types of environmental policies influence innovation.

We also consider the foreign equity ratio in each firm, since a few previous studies claim that domestic firms benefit more from the policy than do foreign competitors (Porter and Van der Linde, 1995; Wei et al., 2005; Yang and Mallick, 2014; Mallick and Sousa, 2017). Incorporating the foreign equity ratio will provide insight into the mechanism of the Porter Hypothesis.

Additionally, we divide firms into different polluting levels, because the Porter Hypothesis' original version is a case study and other relevant empirical articles also focus more on polluting sectors. We take sectors' characteristics into account in order to eliminate these effects. The polluting level divergence is our third difference.

The results of our study align with the Porter Hypothesis. The stricter policy, AQCZ, bolstered the innovation abilities of firms measured by R&D expenditures and patents, while the less stringent one, TCZ, did nothing but impeded firms' innovation. We discuss the mechanism behind this phenomenon and find internal funding is the main source leading to innovativeness.

The remainder of this paper is organized as follows. In the next section, we introduce the Porter Hypothesis and review relevant literature. The third and fourth sections provide model structures and a data description. In the fifth section, we do a series of robustness checks. The sixth section offers our conclusions and a discussion of some political implications.

[2] The full name of the Two Control Zones policy is "Acid Rain Control Zones and Sulfur Dioxide Pollution Control Zones". The covered 1.09 million square kilometers, comprising 175 cities in 27 provinces, accounts for, in total, around 11.4% of China's territory (Hering and Poncet, 2014). The areas covered were the urban-industrial centers, where acid rain stemming from air pollution was becoming an increasingly serious problem. The TCZ policy mainly focused on the quality and usage of combustion fuel, particularly coal, which is the main source of SO_2 and *NOx* emissions (Larssen and Carmichael, 2000). Though the regulations were centralized, the administration was left to each local government. Each city, therefore, had to formulate their own plan to integrate into the TCZ policy and enforce its provisions.

2. Literature review

The cornerstone of the theoretical part in our paper is based on Porter and Van der Linde (1995) that suggests that properly designed environmental regulations can trigger innovation and that the innovation can, in some cases, exceed the costs of complying with the regulations. The first formulation of the Porter Hypothesis, now regarded as the "weak form", focuses only on the question of whether innovation ability will be spurred by environmental regulations (Jaffe and Palmer, 1997). The second formulation in which it is argued that the burden of additional regulatory costs will be or should be fully compensated for by the innovation benefits, is known as the "strong form" of the Porter Hypothesis and is less widely accepted (Ambec et al., 2013). Most papers arguing for the "strong" form of the Porter Hypothesis have failed to confirm its existence (see (Smith and Crotty, 2008; Nemlioglu and Mallick, 2017; Duanmu et al., 2018) etc.). Furthermore, the results for the effects on innovation tend to vary according to the level of analysis (Koźluk and Zipperer, 2013).

Our paper's purpose aligns closer to the "weak form". It should be noted up front that the definitions and metrics used to test the Porter Hypothesis are often contested terrain. There are papers in this stream addressing the relationship between firms' or governments' metrics and the resulting innovation ability. Jaffe and Palmer (1997) find that whether the Porter Hypothesis exists or not depends on the measure of innovation used. Brunnermeier and Cohen (2003) test how the numbers of environmental patents are influenced by pollution abatement expenditures (self-reported) and the number of air and water pollution related inspections. They find the impact is significantly positive although the coefficients are small. Arimura et al. (2007) used the OECD countries' surveying data to test whether environmental R&D data programs were spurred by a series of environmental related factors. The results, again, support the Porter Hypothesis.

For studies at the special country level, Borghesi et al. (2015) test whether the European Emissions Trading Scheme exerted some effects on environmental innovation by using Italian firm-level data and find that those exposed to regulations are more likely to innovate, but sector-specific policy stringency shows negative impacts. Rexhäuser and Rammer (2014) test the case in Germany while distinguishing the effects between regulation-induced and voluntary environmental innovations. They find the positive result holds for both regulation-induced and voluntary innovations, although the effect is greater for regulation-driven innovation. Van Leeuwen and Mohnen (2017) use a tax for energy as a proxy of environmental regulations in the Netherlands, and the results show a strong corroboration of the "weak" form and a nuanced corroboration of the "strong" version of the PH.

There are also some papers examining whether the Porter Hypothesis exists in China. Yang and Yao (2012) used the certification of the ISO14000 as the environmental performance of firms, supporting the "strong form" of the Porter Hypothesis, but using this self-regulated proxy failed to confirm the "weak form". Lin et al. (2014) also sets strings of dummy environmental variables to test if firms' green product innovation and process innovation are affected by them. Their results show that national specific environmental regulations for an industry exert positive effects on firms' green product or process innovation.

We conclude from these studies that R&D and patents are the most used proxies for innovativeness of firms, while few of them adopt specific policies as indicators of environmental regulations. The methods used to test these effects vary from the OLS to DID. We are going to look into the methods in detail and consider how to avoid the endogeneity problem by adopting detailed policies.

3. Empirical model and data

It is a common view that the Difference-In-Differences Model (DID) is efficient and a convenient way to analyze the influence of policies, especially for policies such as AQCZ or TCZ which that vary with the time and regions, and involve two groups: experimental group and control group. There are no studies talking about how to use differential models to discuss the Porter Hypothesis. A few studies use a difference such as List et al. (2003), which uses the DID model to control the presence of unobservables in the research of environmental regulations and Hanna (2010) using DID to research US-based multinationals. Nevertheless, due to the specific target and goal of the environmental policies and regulations involved in our study, we have to introduce one more difference in the interaction term to solve the endogeneity problem. First, we will introduce an improved model and its advantages. Then, the unbalanced panel data of R&D expenditures and patents will be explicated.

3.1. Difference-in-difference-in-differences model specification

The political background indicates that the Chinese cities were divided into two groups: one group under the environmental regulations and the other not. Due to the centralized political system in China, two environmental regulations mentioned above were both implemented around the country at the same time. This leads our dataset to a treatment group and a control group based on two different time periods: one time period before "treatment" and one time period after "treatment". This condition satisfies the requirements of the Difference-in-Differences (DID) model, where $\overline{y_{11}} - \overline{y_{21}}$ represents the horizontal difference between treatment group and control group before the regulations were launched; $\overline{y_{12}} - \overline{y_{22}}$ represents horizontal difference between the treatment group and control group after regulations were implemented. $(\overline{y_{11}} - \overline{y_{21}}) - (\overline{y_{12}} - \overline{y_{22}})$ can be interpreted as the regulation effect. The DID model can be set as:

$$Invt_{it} = \beta Policy_i \cdot Time_t + \mu_t + \theta_i + X'_{it}\lambda + \varepsilon_{it} \tag{1}$$

where *Invt* stands for two innovation indicators: the number of patents and R&D expenditures. *Policy* is either *TCZ* or *AQCZ*, both being in dummy form. $Policy = 1$ means the firm i is in the control zone and involved in the regulations, while $Policy = 0$ means firm i is not. $Time_i = 1$ refers to the post-policy era while $Time_i = 0$ means the policy has not been implemented. μ_t indexes all firm-invariant features in a certain period year t, such as benchmark interest, GDP, or any other macroeconomic factors. θ_i represents a certain firm $i's$ time-invariant features such as production models, connections with local governments, and so on. Apart from that, the DID model requires a parallel counterfactual trend assumption. This means that firms, no matter whether they are on the regulation lists or not, should have the same trend before the policy is conducted. Thus, another matrix X_{it} is added to supplement other factors that may influence R&D expenditures or numbers of patents of all firms. Greek letters in the regression functions are the ones to be estimated. Here, R&D expenditures are already in log form, so the general OLS method is adopted to estimate the coefficients. And as for the numbers of patents, they are discrete integers. Yaacob et al. (2010) mention that count data such as patents could be more accurately estimated by a quasi-Poisson distribution or negative binominal distribution model.

Nevertheless, there are a few concerns with the DID model. First, the more polluting firms would be more heavily influenced by the regulations. In our data analysis, we discarded finance-related firms as they are less relevant with in terms of pollution. But this still cannot solve the estimation-biased problem, because the rest of the firms' polluting levels vary significantly. Second, we control some time-invariant factors, while the time-varying factors were ignored, which may be correlated with the regressors and may also bias the estimation. Additionally, not only can environmental regulations influence firms but also firms can exert influence to policy designs in some extent (Puyan and Li, 2013).

In light of these concerns, we take pollution intensity into account and adopt the Difference-in-Difference-in-Differences (DIDID) model. We consider three factors: regions (policies implemented or not), time (before and after policies were implemented), and industries (heavy polluting and comparatively less polluting). The model specification is shown below:

$$Invt_{itk} = \beta Policy_i \cdot Time_t \cdot Pollution_k + \sigma_{it} + \omega_{tk} + \varphi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \tag{2}$$

where $Pollution_k$ added to the interaction term is the polluting level of the industry k. $Pollution_k = 1$ indexes that k is a heavy polluting industry while $Pollution_k = 0$ indexes a less polluting one. We distinguish different polluting levels according to the Chinese classification of industries: agriculture, industry, and service. Agriculture and industry tend to be more polluting. The DIDID method helps us to control more factors so we control province-year, year-industry, and industry-province fixed effects. σ_{it} captures the province-year effects of a firm. We use province-year level data because firms in the same province could show a number of common features such as tax deduction and minimum wage requirements among others. Also, in our later maximum likelihood estimation, too many dummies set can easily cause dispersion, resulting in a biased estimation. ω_{tk} represents year-industry fixed effects. We divided firms into five industry groups according to their register information in the Shanghai Stock Exchange and Shenzhen Stock Exchange such as real estate, and public service. ϕ_{ki} stands for industry-province fixed effects. By controlling industry-province effects, we allow industries to vary across different provinces. Although power-centralized China often chooses to implement a policy across the whole country at the same time regardless of regional difference, it is the provincial government who chooses to implement the policy. Last, ε_{itk} is the error item.

In the estimation, $(y_{\overline{P}11} - y_{\overline{P}21}) - (y_{\overline{P}12} - y_{\overline{P}22})$ can be interpreted as the regulation effects on polluting firms. $(y_{\overline{N}11} - y_{\overline{N}21}) - (y_{\overline{N}12} - y_{\overline{N}22})$ shows the regulation effects for the less polluting firms. We set one more difference based on our previous model to generate $\{(y_{\overline{P}11} - y_{\overline{P}21}) - (y_{\overline{P}12} - y_{\overline{P}22})\} - \{(y_{\overline{N}11} - y_{\overline{N}21}) - (y_{\overline{N}12} - y_{\overline{N}22})\}$ to reflect how the spillover of regulations impacts polluting firms compared to less polluting ones.

With a series of sub-items of patents introduced to represent different innovation levels, we could develop further research into the Porter Hypothesis in detail. The sub-items of patents models are set as:

$$\begin{aligned} Pat\_Sub_{itk} = \beta Policy_i \cdot Time_t \cdot Pollution_k + \sigma_{it} \\ + \omega_{tk} + \varphi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \end{aligned} \tag{3}$$

In this function, *Pat–Sub* means the sub-items of patents: invention, utility model, and design. In the DIDID model, the most important coefficient is the interaction coefficient β, which is the expression of the treatment effect. If cities selected into the regulation list are independent of the variable matrix X_{itk}, or are expressed as $E(\varepsilon_{itk} \mid TCZ_i \cdot Time_t \cdot Pollution_k, X_{itk}) = 0$, we can get an unbiased estimation of the coefficient β. But in realistic political cases, we only require that $\varepsilon'_{itk}s$ expectation is zero given policy to also get unbiased estimation.

As mentioned, there are two concerns. First, the number of patents are discrete. A proper way to utilize the discrete data is to construct a Poisson Regression Model or when under- or over-dispersion exists, adopt the Negative Binomial Regression Model. Nevertheless, there is little probability that the mean and variance of the numbers are same. The distribution of the numbers of patents usually has a variance that is not equal to its mean and disobeys the Poisson distribution. The variance of a Quasi-Poisson model is a linear function of the mean while the variance of a negative binomial model is a quadratic function (Ver Hoef and Boveng, 2007). Here, we adopt the Quasi-Poisson regression.

We also investigate if foreign companies or foreign-capital invested companies will perform better in innovativeness because if so, foreign companies or foreign equity may prevail under such environmental regulations. The Porter Hypothesis' derivative conclusion is that domestic firms behave better. Greaker (2003) shows that if the domestic firms benefit from reducing marginal costs and the environmental regulations are the commitment device for them to invest in R&D, then the domestic firms get more competitive in international markets compared to foreign firms. Due to the separation of ownership and management in modern corporations, the foreign equity ratio in each year is an important factor influencing daily operations (Huang and Zhu, 2015; Zhang et al., 2019). So, in order to determine if foreign equity can influence innovation abilities, each firm's foreign equity ratio in each year is considered as a part of the matrix. Other factors are the assets of each firm, which represents the accumulated affects, and the age of the firm measured as the years since the firm was built up. Old firm can be considered as authentic in their field and with more experience.

3.2. Data description

3.2.1. Environmental regulation data

The measurement of environmental regulations comes from two detailed policies that the Chinese government implemented in 1998 and 2012, respectively, the Two Control Zones and the Air Quality Control Zones, which mainly concentrated on air pollution, but were introduced with different backgrounds and purposes. The cities involved in these two policies are mapped in the appendix. Another concern is regard to the time ranges we adopt to test the policies. Longer test period can help to draw a more general conclusion. Nevertheless, since the AQCZ policy is a part of the Twelfth Five-year Plan, which is a serial plan conducted every five years, testing longer than 10 years may lead to a biased conclusion, because of the overlap of two policies. Thus, we choose 1995–2005 and 2006–2015 as the test periods for the two policies, so that these two policies will not impact each other's test results.

As we adopt the Difference-in-Difference-in-Differences method, the firms in the policy-implemented areas are set with a dummy variable equal to 1. For the time dummies, we set the value for the first year after the policy is put forward and thereafter as value 1 and 0 for the first year and those before. The polluting level of a firm is measured according to the industry they are in. The polluting level of a firm is measured according to the industry they are in, using the Chinese Classification of Industry codes.

Due to the fact that the environmental policies were conducted by regions, In the selection process of our samples, we must take into account that some firms may headquarter in one place but have multiple factories. When firms face stricter regulations in environmental production, which is a form of increased cost in production, they have to decide either bear the higher cost or transfer their production to other planets outside the areas facing the regulations. However, according to previous studies both in developed and developing countries, when firms face the increase of the cost in production in a comparatively short period, which is close to the length we adopt in our paper, the transfer in production is limited (Kirkegaard, 2007; Koch and Basse Mama, 2016). In addition, in the selection of the samples, we drop all observations which are in some specific industries, which could have their products covering multiple regions such as utility companies or oil and gas enterprises in order to further avoid the caveats mentioned.

3.2.2. Innovation data

The R&D and patents are derived from the CSMAR database, which offers data on the financial statements of Chinese listed companies. Due to the limitation of data collection, the R&D expenditure is only testable for the Air Quality Control Zones policy. Another shortcoming of R&D data is that we cannot further explore the details of the R&D expenditures, due to the complexity and high uncertainty of R&D activities. They are also the reasons why most recent papers focus more on the patents, which is also the genre we follow. Apart from that, there are a few characteristics we take into account when processing the data. First, the financial enterprises are not in our consideration, since they are less relevant for production. Second, both our datasets, the R&D and patents, are unbalanced. The time ranges of the tests of the two policies cover long periods. So there are firms that already existed before the policies started, and some firms entered during the periods.

Table 1 gives the statistical description of our R&D and patent data. The new Accounting Standard for Business Enterprises released in 2007 required firms to report their R&D expenditures. It stated that firms could but were not legally being asked to disclose the amount of R&D expenditures in the reports. Thus, the comprehensive R&D data of listed firms are available from 2010 to 2015, but here, only data after 2011 is collected since too few firms provided data in 2010.

The patent data of listed firms are available from 1994 to 2015. Chinese patents can be categorized into three types: Invention, Utility Model, and Design. According to the explanation of the State Intellectual Property of China, invention means any new technical solutions relating to a product, a process or an improvement. A utility model means any new solution relating to the shape, structure, or their combination of a product that is fit for practical use. Industrial design means any new design regarding the shape, pattern, or their combination, which creates an aesthetic feeling and is fit for industrial application Office (b).[3]

The numbers of utility model and design are far greater than invention. In addition, the utility model is also the fastest-growing one, as it is granted quickly and easily. A utility model usually receives preliminary examination, but substantial examination is not required. Table 2 shows the difference of protected matter, term of patents, form of examination, and relevant fees (Office, a). The requirements in each step make the number of inventions much lower than utility model and design patents. It usually takes one to one-and-a-half years for the office to approve the invention application, and the utility model or design application takes less than six months (Cheung and Ping, 2004). Thus, inventions are regarded as the truly innovation.

4. Empirical results

We are representing our DIDID results in this section. First, due to the actuality of the rules in China, only the AQCZ policy is tested for R&D expenditures. Both the TCZ and AQCZ policies are tested for whether they had impacts on the number of patents of a firm.

4.1. R&D expenditure results

Table 3 shows the regression results of how the AQCZ policy influences R&D expenditures with no fixed effects controlled, only province-year fixed effects controlled and all three interaction terms controlled. We find when all three interaction terms are controlled, the interaction coefficients are significantly positive. This means the AQCZ policy prodded firms into more research and developing activities.

From the regression results, the foreign equity in management coefficient also shows a significant and positive sign. This suggests that foreign equity also plays an important role in the R&D decision. The higher the percent of foreign equity in management, the greater the probability that firms are willing to put more capital into R&D activities. The result violates part of the Porter Hypothesis because what we get from that hypothesis is that domestic firms or domestic equity dominating firms are more familiar with rules or laws, so they tend to adjust to the new regulations faster than their opponents. However, R&D is a willingness to increase the innovation ability. There is also a possibility that under the same regulation, foreign firms face more challenges to decrease the pollution level in production or increase production efficiency. Another famous phenomenon is that China has strict capital flight controls which leads foreign firms to invest more in R&D activities because it is often costly and tough for global companies to remit money back to home countries. A wise idea is to set the research and develop center in China, which is usually high-cost and with few

[3] The Chinese invention patent is somewhat similar to the utility one in the United States. The Chinese utility model patent is similar to the European and Japanese ones. There is no counterpart for the utility model patent in the US.

Table 1
Statistical description of R&D and patents.

Variables	Observations	Mean	Std. Dev.	Min	Max
R&D expenditures					
Total	8783	1.4173×10^8	9.3642×10^8	0	7.3839×10^{10}
Observations dropped	166	1.3031×10^8	7.7483×10^8	0	1.6200×10^9
Regression samples	8617	1.4195×10^8	9.3926×10^8	0	7.3839×10^{10}
Patent numbers					
Total	16,041	5.90	40.02	0	2551
Observations dropped	6370	3.62	27.83	0	245
Regression samples	9671	7.40	46.33	0	2551
Invention					
Total	16,041	0.01	0.11	0	6
Observations dropped	6370	0.01	0.07	0	2
Regression samples	9671	0.01	0.13	0	6
Utility model					
Total	16,041	4.32	34.14	0	2549
Observations dropped	6370	2.49	23.57	0	219
Regression samples	9671	5.51	39.59	0	2549
Design					
Total	16,041	1.58	11.56	0	617
Observations dropped	6370	1.06	8.58	0	95
Regression samples	9671	1.92	13.16	0	617
Assets	11,953	4.6269×10^{10}	6.4543×10^{11}	1.5454×10^7	1.9500×10^{13}
Foreign equity ratio	9067	0.60	0.1600	0.01	1.00

Note: The R&D data covers the period from 2011 to 2015, which only is used to discuss the AQCZ policy. The patent data, which includes invention, utility model, and design, cover the period from 1995 to 2015. The patent data will be used to test both the TCZ and AQCZ policies, where 1995–2005 and 2006–2015 are for the TCZ and AQCZ, respectively. The total observations of R&D expenditures and patents include observations with R&D expenditures and patents information. The dropped observations include financial firms, service firms involving no productions, and firms with multiple allocations of plants.

physical outputs. This could help foreign invested companies save a significant tax costs or remit fees. Thus, only through R&D expenditures view, it is still difficult to draw a conclusion on whether foreign firms are more environmentally responsible or more easily being encouraged to develop new technologies under environmental restrictions.

4.2. Patent number results

First, we test how the AQCZ policy influences total patent numbers and three sub-items. Table 4 presents results with no fixed effects controlled for, only province-year effects and three interaction terms are controlled. The test results with three effects controlled again favor of the Porter Hypothesis. Interaction coefficients are significantly positive no matter if other possible factors are considered or not.

However, we find that for the numbers of patents, foreign equity in management actually does not have any influence. The sign on the foreign equity coefficients indeed show no significance levels. This result violates the derivative conclusion of the Porter Hypothesis, but actually several empirical studies find that the characteristics of a firm's capital structure has no influence on its environmental impact or pollution disposal. Tang and Li (2009) uses Corporate Social Responsibility (CSR) to measure several social responsibilities of Chinese domestic companies and global companies, including environmental responsivity, but find that there is no significant difference in their emphasis on environmental conservation.

It is also necessary to consider the sub-items of patents if we want to learn more about the Porter Hypothesis' mechanism. As stated in the data description, the requirements and amount of sub-parts vary a lot between these three items. Most of time, utility model accounts for the highest ratio of the total patents, and in a certain period, design also dominated the patent number. Next, we run a regression of how the AQCZ policy influenced three sub-items with all three fixed effects controlled (See Table 5).

First, the utility model shows similar results with total patents. We know that after 2010 the utility model accounts for nearly 70 to 80 percent of total patents so there is no surprise that the AQCZ policy exerts significant and positive effects on the numbers of utility models. But it also shows that foreign equity has negative effects on the utility numbers. This means that firms with a higher ratio of foreign equity are not willing to develop low quality innovations. An interesting finding is, therefore, that inventions are neither promoted nor impeded by the environmental regulations, nor are inventions influenced by the ratio of foreign equity in a firm's management. The utility model is often called "Invention Lite", as it shows a similar purpose as an invention but with much lower standards or requirements. Thus, when confronting the strict regulations, firms may choose to adopt the low-cost utility models, considering the marginal costs and benefits. Firms choose low cost utility models, to reduce the pollution emissions or increase productivity when there is a target set for emissions. When it comes to design, we find that the regression results indicate that the number of designs are significantly and negatively influenced by the environmental regulations. Design patents only focus on the appearance of a product rather than the quality or efficiency. Under the limited budgets and strict environmental regulations, pragmatic firms would rather choose to put more weight on utility models, which is consistent with our intuition. When we consider the foreign equity ratio in management, it shows foreign equity promoted the creation of design.

Next, we look at the TCZ policy. Table 6 presents regression models without fixed effects controlled, only province-year effects controlled, and where all three effects are controlled. Contrary to the AQCZ policy, the TCZ imposes negative effects on the number of patents. This finding violates the Porter Hypothesis.

This result may have two possible reasons. First, as mentioned with the Porter Hypothesis, the environmental policy should be well designed and strictly conducted. The TCZ policy, set to control the SO_2 emissions with a specific target is one thing, but whether it was

Table 2
Summary of three types of patents in China.

Type of Patents	Protected matter	Maximum term	Form of examination	Application fee (RMB)	Examination fee (RMB)	Surcharge (RMB)
Invention	Inventive ideas realized as product and/or method	20 years	Substantive examination	900	2500	Surcharge for claims in excess of 10 (per claim): 150; Surcharge for specification in excess of 30 pages (per page): 50; Surcharge for specification in excess of 300 pages (per page): 100
Utility model	Inventive ideas realized as product	10 years	Preliminary examination	500	No	Surcharge for claims in excess of 10 (per claim): 150; Surcharge for specification in excess of 30 pages (per page): 50; Surcharge for specification in excess of 300 pages (per page): 100
Design	Aesthetic features, i.e. the appearance of a product	10 years	Preliminary examination	500	No	Surcharge for claims in excess of 10 (per claim): 150; Surcharge for specification in excess of 30 pages (per page): 50; Surcharge for specification in excess of 300 pages (per page): 100

Table 3
DIDID regression of R&D expenditure concerning the AQCZ.

	R&D expenditures					
AQCZ·Time·Pollution	0.3060*** (0.0288)	0.4313*** (0.0318)	0.3047*** (0.0439)	0.5410*** (0.0483)	0.4774*** (0.0631)	0.5836*** (0.0730)
Other Control Variables:						
Asset (log)	0.6318*** (0.0134)	–	0.6338*** (0.0131)	–	0.6640*** (0.0129)	–
Foreign Equity in Management	0.4338*** (0.0961)		0.36302*** (0.0941)		0.4540*** (0.0908)	
Years since established	−0.2815*** (0.0369)		–		–	
Province-Year Effects	NO		YES		YES	
Year-Industry Effects	NO		NO		YES	
Industry-Province Effects	NO		NO		YES	
Observations	6987	8617	6987	8617	6987	8617
Number of Firms	1811	2289	1811	2289	1811	2289
R-Square	0.2529	0.0209	0.3167	0.0773	0.3930	0.1486

Notes: Robust standard errors in parentheses. Significant at *10%, **5%, ***1% confidence levels. The time range for the AQCZ policy is 2011–2015. The dependent variable is R&D expenditures for these specifications. The table shows marginal effects.

implemented strictly is another matter. So, if the policy was not implemented in a proper way, it violates the prerequisite of the Porter Hypothesis. Second, it is also possible that the Porter Hypothesis does not work for that period's macroeconomic background. Next, we look at details of how the patent sub-items are influenced by the TCZ policy (see Table 7).

First, the number of inventions before 2005 for most of firms is zero. From the regression results, we find that it is okay to skip the invention patents. The number of utility models shows no significant level in the signs, but design was significantly and negatively influenced by the TCZ policy when other control variables were added. From the data description, we could see that around the year 2000, designs dominated the total patents. Hence, when designs decreased due to the TCZ policy, the sign on total patents became negative.

4.3. *The mechanism triggering innovativeness*

Regarding how to simulate innovativeness, existing models implicitly assume that firms can fund innovation activities at no cost. In reality, nevertheless, innovative firms face financing frictions. There are a few theories about what could trigger firm innovativeness such as policy simulating industry-generated information, which reduces long-term uncertainties and provides flexibility (Norberg-Bohm, 1999). However, there are studies that note that in a freely competitive market,

Table 4
DIDID regression of patent number concerning the AQCZ.

	Patent numbers (Quasi-Poisson regression)					
AQCZ·Time·Pollution	0.8360***	0.9517***	0.7614***	1.0246***	0.2688**	0.5199**
	(0.0545)	(0.0993)	(0.0998)	(0.1793)	(0.1224)	(0.2215)
Other Control Variables:						
Asset (log)	0.6335***	–	0.6800***	–	0.6880***	–
	(0.0154)		(0.0134)		(0.0135)	
Foreign Equity in Management	−0.1084		0.0415		−0.0411	
	(0.1572)		(0.1305)		(0.1287)	
Years since established	0.2040***		–		–	
	(0.0759)					
Province-Year Effects	NO		YES		YES	
Year-Industry Effects	NO		NO		YES	
Industry-Province Effects	NO		NO		YES	
Observations	7944	7944	7944	7944	7944	7944
Number of Firms	1488	1488	1488	1488	1488	1488

Notes: Robust standard errors in parentheses. Significant at *10%, **5%, ***1% confidence levels. The time range for the AQCZ policy is 2006–2015. The dependent variable is the number of patents for these specifications. The table shows marginal effects.

Table 5
DIDID regression of sub-items number concerning the AQCZ.

	Patent numbers (Quasi-Poisson regression)					
	Invention		Utility model		Design	
AQCZ·Time·Pollution	−0.0154	−0.0150	0.6076***	0.9073***	−0.4626***	−0.3767**
	(0.0102)	(0.0100)	(0.1270)	(0.2586)	(0.1300)	(0.1648)
Other Control Variables:						
Asset (log)	0.0024*	–	0.7095***	–	0.4490***	–
	(0.0014)		(0.0127)		(0.0184)	
Foreign Equity in Management	0.0157		−0.2977**		0.5864***	
	(0.0106)		(0.1208)		(0.1661)	
Province-Year Effects	YES		YES		YES	
Year-Industry Effects	YES		YES		YES	
Industry-Province Effects	YES		YES		YES	
Observations	7944	7944	7944	7944	7944	7944
Number of Firms	1488	1488	1488	1488	1488	1488

Notes: Robust standard errors in parentheses. Significant at *10%, **5%, ***1% confidence levels. The time range for the AQCZ policy is 2006–2015. The dependent variable are the numbers of the sub-items of patents including inventions, utility models, and designs for these specifications. The table shows marginal effects.

it is hard to spark innovation (Bournakis et al., 2018). Thus, intellectual property protection, subsidies, and tax incentives from the government are important to prompt firms to follow the rules. When facing regulations, firms tend to finance innovation activities internally, and Bournakis and Mallick (2018) find that firms using leverage to fund R&D suffer more than other firms when facing economic distress. Due to the uncertainty of R&D investment, the capital structure of innovative firms customarily exhibits considerably less leverage than that of other firms. Banks and other debtholders prefer to use physical assets to secure loans and are reluctant to support innovation activities (Hall, 2002).

When facing external pressure, Atanassov (2015) further finds that different financing methods affect firms' incentives to innovate and arm's length financing is a more efficient way to finance innovation

Table 6
DIDID regression of patent number concerning the TCZ.

	Patent numbers (Quasi-Poisson regression)					
TCZ·Time·Pollution	−0.0597	0.2422*	−0.0598	−0.0597	−0.3156**	−0.2834*
	(0.1353)	(0.1414)	(0.1248)	(0.1353)	(0.1444)	(0.1551)
Other Control Variables:						
Asset (log)	0.2306***	–	0.2470***	–	0.2636***	–
	(0.0431)		(0.03448)		(0.0347)	
Years since established	0.4251***		–		–	
	(0.1062)					
Province-Year Effects	NO		YES		YES	
Year-Industry Effects	NO		NO		YES	
Industry-Province Effects	NO		NO		YES	
Observations	1627	1627	1627	1627	1627	1627
Number of Firms	488	488	488	488	488	488

Notes: Robust standard errors in parentheses. Significant at *10%, **5%, ***1% confidence levels. The time range for the TCZ policy is 1995–2005. The dependent variable is the number of patents for these specifications. The table shows marginal effects.

Table 7
DIDID regression of sub-items number concerning the TCZ.

	Patent Numbers (Quasi-Poisson regression)					
	Invention		Utility model		Design	
TCZ·Time·Pollution	0.0000***	0.0000	−0.0627	−0.0543	−0.3032**	−0.2718*
	(0.0000)	(0.0000)	(0.0453)	(0.0473)	(0.1480)	(0.1579)
Other Control Variable:						
Asset (log)	0.0000***	–	0.0751***	–	0.2439***	–
	(0.0000)		(0.0123)		(0.0353)	
Province-Year Effects	YES		YES		YES	
Year-Industry Effects	YES		YES		YES	
Industry-Province Effects	YES		YES		YES	
Observations	1627	1627	1627	1627	1627	1627
Number of Firms	488	488	488	488	488	488

Notes: Robust standard errors in parentheses. Significant at *10%, **5%, ***1% confidence levels. The time range for the TCZ policy is 1995–2005. The dependent variable is the number of patents including inventions, utility models, and designs for these specifications. The table shows marginal effects.

activities. In addition, compared with external financing, using internal financing results in a faster way to response regulations with innovation outcomes (Zingales and Rajan, 2003). Thus, we think for these firms under the environmental regulations, they tend to use internal financing in order to quick response to the requirements from the government. In this part, we test whether the environmental regulation forces firms to set fluid assets to innovate. We consider the profit ratio, which is measured by the fraction of annual profit to assets. The higher this ratio, the more fluid funds a firm has for innovation activities.

$$Invt_{itk} = \beta(AQCZ_i \cdot Time_t \cdot Pollution_k) \cdot RoP_{itk} + \sigma_{it} + \omega_{tk} + \varphi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \tag{4}$$

where RoP_{itk} stands for the profit ratio, which is set as part of the interaction term. This makes it possible for our models to reflect the change of fluid funds a firm holds. We test both R&D expenditures and the total number of patents and sub-items. The results are shown below (see Table 8).

The results from the table above display the same significant levels and signs as previous ones when we have all three fixed effects controlled. In addition, the values of the coefficients are larger than our previous regressions without consideration of liquidity at firm level. For instance, the coefficient of R&D expenditures is 15% larger than the previous result and even larger effects can be seen regarding patents partly due to the scales changed. The results are in line with previous studies and our hypothesis. Previous studies mention that R&D is hard to finance with external funds because it is not pledgeable, uncertain, and involves trials and errors (Kerr and Nanda, 2015). Chinese economic background could further affirm this assumption since state-owned banks are more unwilling to lend money for innovation activities. It means that it is more possible that the policy first affects firms' cash flow, making firms set more internal funds toward innovate. However, for those firms without enough abilities to finance internally but facing environmental regulations, the limited resource impinges on their willingness to innovate but will not deflect them from innovation activities.

5. Robustness check

In the research on the impacts of the policies, we are concerned about the endogeneity problems that exist, which may lead to biased estimations. Our DIDID model solves the likelihood of the policy dummy variables being correlated with the error term. In spite of that, we could improve the accuracy of the estimation by considering the likely omitted variables and strengthen the results by using a placebo test.

5.1. Policy stringency

In our previous analysis, the policies are set as dummy variables. Actually, the policies cannot be conducted by the local governments with same stringency, even though they have the same standards. According to Hübler et al. (2014) and Wu et al. (2017) in China, different GDP levels in different areas and different sectors lead to different efficiency in conducting environmental policies. Considering

Table 8
DIDID regression testing the mechanism.

	R&D expenditure	Patent numbers	Invention	Utility model	Design
(AQCZ·Time·Pollution)·RoP	0.5491***	3.9342***	−0.0227***	3.8297***	3.3651**
	(0.0659)	(0.3104)	(0.0353)	(0.2967)	(0.4238)
Other Control Variables:					
Asset (log)	0.6713***	0.7095***	0.0023	0.7336***	0.4589***
	(0.0129)	(0.0130)	(0.0014)	(0.0122)	(0.0183)
Foreign Equity in Management	0.4596	−0.1745	0.0165	−0.4306***	0.4314***
	(0.0906)	(0.1240)	(0.0106)	(0.1167)	(0.1658)
Province-Year Effects	YES	YES	YES	YES	YES
Year-Industry Effects	YES	YES	YES	YES	YES
Industry-Province Effects	YES	YES	YES	YES	YES
Observations	6987	7309	7309	7309	7309
Number of Firms	1811	1481	1481	1481	1481
R-Square	0.3976	–	–	–	–

Notes: Robust standard errors in parentheses. Significant at *10%, **5%, ***1% confidence levels. The time range for the AQCZ policy is 2006–2015. The dependent variables of the specifications are the R&D expenditures and the number of patents and sub-items of patents for these specifications. The table shows marginal effects.

this, we need to distinguish to which extent a firm is influenced by a certain policy. Here, referring to Wu et al. (2013), we use the fraction of expenditures the province government spent on combating air pollution to the total annual budget as the indicator for policy stringency. We use the new item $AQCZ^{str}$, which reflects the regulation stringency a firm is confronted with, to replace the previous dummy variable. The $AQCZ^{str}$ is the product of policy dummy and policy stringency: $AQCZ_i^{str} = AQCZ_i \times Stringency_j^{policy}$, where $Stringency_j^{policy} = Expenduture\ in\ Combating\ Air\ Pollution_j / Annual\ Budget_j$. The government system in China determines that this fraction might vary across provinces, as the province level government has more power to determine the annual targets for pollution control. We can then construct our new model considering the policy stringency:

$$Invt_{itk} = \beta AQCZ_i^{str} \cdot Time_t \cdot Pollution_k + \sigma_{it} + \omega_{tk} + \varphi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \quad (5)$$

Here, we present our results of the test of the AQCZ policy (see Tables 9 and 10):

In the regression results, the interaction terms of both patents and R&D expenditures are still significant. Though we find the R-Squared of R&D expenditures is larger than in our previous regressions and that the significant levels are both higher, the difference is tiny. By these findings, we can exclude the possibility that local governments did not conduct the policy strictly. Our dataset shows that there is some difference among the fractions of expenditures on solving air pollution in the different provinces. The highest percent occurred in Heilongjiang in 2011, which reached 5.99%. The lowest was in Tibet in 2007, which only accounted for 0.007% of the total budget. But as mentioned above, the AQCZ is a national-wide policy and the same standards were applied to all cities involved. The variance of fractions is only 0.073%, which is small, and it becomes even smaller after 2012, 0.054%. All in all, the stringency of conducting policy is not a big problem for us to consider in our research topic.

Centralized environmental policies have been proved efficient. Wallace (2017) explores six developed OECD countries: Denmark, the Netherlands, Germany, France, Japan, and the US. Even though these countries have decentralized systems, a series of national/federal level environmental policies were conducted in the 1900s. These countries' innovation was successfully harnessed by setting credible, long-term environmental goals and ensuring that regulatory instruments are grounded in flexibility, dialogue, and trust. This shows consistence between developed and developing countries and centralized and decentralized government systems.

5.2. Lags and leads effects

In our DIDID model, we used interaction terms to control the time trend effects. But another concern is the timing of the change in environmental regulations. First, the AQCZ policy must take several years to make a plan. Before the regulations were released, some firms might get information and prepare for it in advance. Second, the introduction of the AQCZ policy might have sustained effects, and it also costs firms

Table 9
DIDID regression of patent number concerning the AQCZ stringency.

	Patent Numbers (Quasi-Poisson regression)					
AQCZ_str·Time·Pollution	0.3189***	0.3322***	0.6396***	0.5874***	0.2219**	0.3087**
	(0.0312)	(0.0604)	(0.0901)	(0.1382)	(0.1017)	(0.1493)
Other Control Variables:						
Asset (log)	0.6393***	–	0.6898***	–	0.6924***	–
	(0.0165)		(0.0133)		(0.0135)	
Foreign Equity in Management	0.0420		0.0979		−0.0219	
	(0.1674)		(0.1297)		(0.1279)	
Years since established	0.3084***		–		–	
	(0.0809)					
Province-Year Effects	NO		YES		YES	
Year-Industry Effects	NO		NO		YES	
Industry-Province Effects	NO		NO		YES	
Observations	7944	7944	7944	7944	7944	7944
Number of Firms	1488	1488	1488	1488	1488	1488

Notes: Robust standard errors in parentheses. Significant at *10%, **5%, ***1% confidence levels. The time range for the AQCZ policy is 2006–2015. The dependent variable is the number of patents for these specifications. The table shows marginal effects.

Table 10
DIDID regression of R&D expenditure concerning the AQCZ stringency.

	R&D Expenditure					
AQCZ_str·Time·Pollution	0.1090***	0.1606***	0.3022***	0.3829***	0.3395***	0.3520***
	(0.0176)	(0.0196)	(0.0346)	(0.0388)	(0.0471)	(0.0549)
Other Control Variables:						
Asset (log)	0.6356***	–	0.6412***	–	0.6715***	–
	(0.0134)		(0.0131)		(0.0129)	
Foreign Equity in Management	0.4338***		0.3759***		0.4605***	
	(0.0966)		(0.0938)		(0.0907)	
Years since established	−0.2599***		–		–	
	(0.0370)					
Province-Year Effects	NO		YES		YES	
Year-Industry Effects	NO		NO		YES	
Industry-Province Effects	NO		NO		YES	
Observations	6987	8617	6987	8617	6987	8617
Number of Firms	1811	2289	1811	2289	1811	2289
R-Square	0.246	0.007739	0.3232	0.0767	0.396	0.1484

Notes: Robust standard errors in parentheses. Significant at *10%, **5%, ***1% confidence levels. The time range for the AQCZ policy is 2011–2015. The dependent variable is R&D expenditures for these specifications. The table shows marginal effects.

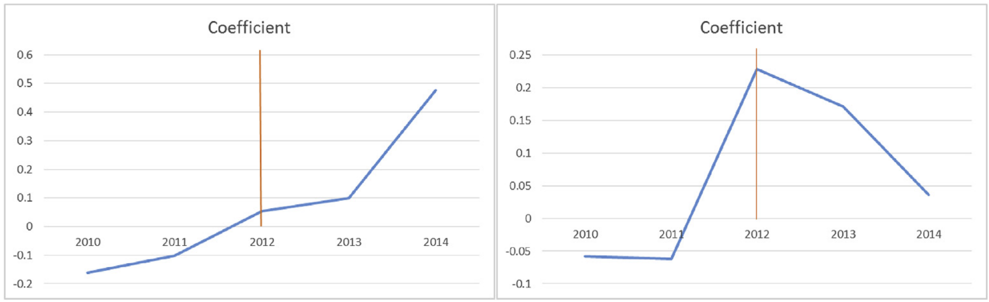

Fig. 1. Time changing coefficients (Left: R&D expenditures, Right: patent numbers).

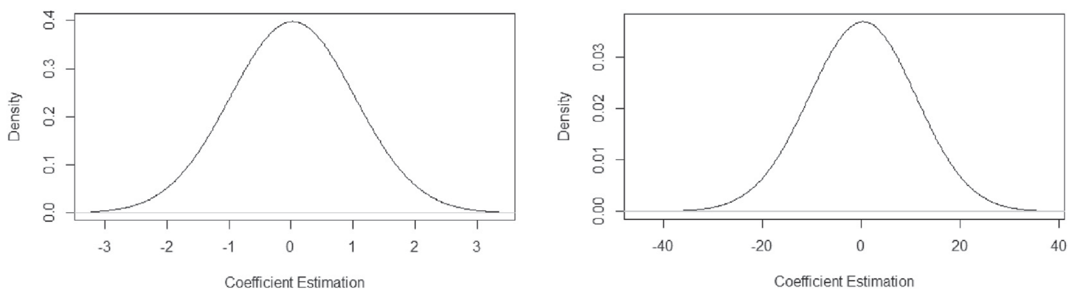

Fig. 2. Distribution of coefficient estimation density (Left: R&D expenditures, Right: patent numbers).

a period of time for them to improve their innovation ability. Hence, it is necessary to take lags and leads terms into account in our model. Following Laporte and Windmeijer (2005), the DIDID model with lags and leads terms are explicated below:

$$Invt_{itk} = \sum_{t=-2}^{2} \beta_{2012+t} AQCZ_i \times Time_{2012+t} \times Pollution_k + \sigma_{it} + \omega_{tk} + \varphi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \quad (6)$$

where $Time_{2012+t}$ is the indicator for year 2012 + t. We set two years forward and two years backward with the default year of 2012 so that coefficients β_{2012+t} captures two years lag to two years lead effects. We plot the results of the coefficients (see Fig. 1).

From the figures above, no matter R&D expenditures or patent numbers, we can notice that there are no leads effects from the environmental regulations. Before 2012, the coefficients are negatively related with both dependent variables. Then after 2012, the coefficients of both R&D expenditures and patents become to positive. The coefficients in the time changing DIDID models are very similar with the original models in the default year. This means that after the policy was released did firms start to realize the importance of environmental innovation. This reflects a common phenomenon in China that, before the AQCZ policy, policies are often considered as a slogan rather than real implementation. However, the AQCZ policy was conducted differently from previous ones, and firms are forced to put more capital into R&D development or patenting activities. We could draw a conclusion that the effects of the AQCZ policy are immediate. A divergence in trend occurs after 2012 between R&D expenditures and the number of patents. Although the AQCZ policy coefficients are still positive, the AQCZ policy exerts a larger and larger influence on R&D expenditures with contrary trend effects on the number of patents.

5.3. Placebo test

In order to make our findings more solid, we decide to test to see if the AQCZ policy is the key factor that leads to the increase in R&D expenditures or the number of patents. We conducted the placebo test according to same method provided by Chetty et al. (2007). In our data sample, there are 3198 listed firms in total, and 2468 firms, or 77.18% are involved in the AQCZ policy. We stochastically set 77.18% of the total firms as the AQCZ policy influencing ones, in other words, those whose dummy variable for AQCZ policy equals 1, and the rest are set as 0. This step eliminates the effects of the AQCZ policy. We rule out incomplete samples in different regression models.

We run 1000 loops to randomly set the AQCZ policy dummy variable value each time and get the results of the interaction term coefficients. We draw the distribution of the coefficient estimation density and find either the coefficient of R&D expenditures or the number of patents obeys a normal distribution with mean values of zero (see Fig. 2).

By this placebo test, we confirm that the AQCZ policy did influence the firms' innovativeness, and the former significantly positive effects of interaction term are caused by the implementation of AQCZ policy to some extent.

6. Conclusion

This paper considers two recent Chinese pollution control regulations, the TCZ policy in 1998 and the AQCZ policy in 2012, to test whether environmental regulations can spur firm innovativeness in China. The results indicate that only well-designed and more strictly implemented policies show efficiency, which aligns with the Porter Hypothesis. The impact of the two policies in our study is identified by the comparison of the outcome variables for the AQCZ/TCZ cities in intensively polluting industries vis-á-vis clean industries for Non-AQCZ/Non-TCZ cities before and after the policies were implemented. This method is based on our DIDID model, which helps control the factors leading to endogeneity problems. We have taken an important step toward resolving the potential endogeneity in other forms of Porter Hypothesis testing.

We use firm-level R&D expenditures and the numbers of patents as indicators of innovativeness. We distinguish the polluting level of a firm according to the industry it is in and control three interaction terms in DIDID regressions. Our results show that the AQCZ policy, the second and more centralized policy did increase both R&D expenditures and the total number of patents among affected firms. The TCZ policy, a less comprehensive plan, actually had a negative effect on the numbers of patents. We then look at the patent outcomes by quality to further explore this result. The AQCZ policy triggered an increase of mostly low-quality patents, while the TCZ reduced the number of patents across the board with a comparatively more negative impact on the low-quality patents, which are the most frequent but least correlated with innovation. The strongest finding in our study is that the higher the ratio of foreign equity in a Chinese listed firm, the greater that firm's R&D expenditures. Although there was no correlation between the ratio and the number of patents firms produced, the fact that non-Chinese firms are showing a willingness to invest in Chinese R&D is itself interesting and ripe for further exploration. Due to the limit of information available and technical issues regarding how the government monitors firms' emissions and fines them for violations in China, we cannot further explore the direct mechanisms in detail but had a glimpse into it from firms' corporate performance. However, the burgeoning of awareness of the environment in China provides us the vision to discuss this topic in the near future. Though we do not resolve the endogeneity and other concerns entirely, we believe our paper makes an important methodological contribution to the research in the area of environmental policy and innovation.

Appendix

Fig. 3 Two Control Zones (TCZ) policy area, 1998.

Fig. 4 Air Quality Control Zones (AQCZ) policy area, 2012.

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