Regulation, Innovation, and the Porter Hypothesis: Examining Outcomes in Chinese Pollution Control Policy Areas

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Abstract

The Porter Hypothesis – debated by economists alike over the past 25 years posits that well-designed environmental regulation can induce innovation in competitive industries. In this paper, we examine how two regionally implemented environmental initiatives in China have im-

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pacted the innovation ability of Chinese-listed firms. The regional implementation of these policies, with non-policy regions serving as a control, offers researchers the perfect conditions for a natural experiment. We use a novel Difference-In-Difference-In-Difference (DIDID) method to eliminate endogeneity. Using R&D expenditures and patents to measure innovativeness, we compare the record of innovation of firms inside the policy zones with firms outside the policy zones. We also take the quality of the patents into account by adopting sub-items of patents. Results show only one of the regulations had a positive effect on firms' innovativeness, and that low quality patents account for most of the innovation. We set a series of robustness checks, which help to solidify our results. We conclude that reasonably designed environmental regulations, implemented regionally in competitive industries, do improve Chinese firms' innovation ability in line with the Porter Hypothesis.

Key Words

Environmental Regulations; Innovation; Porter Hypothesis; Difference-In-Difference-In-Differences Estimation

JEL Classification Codes

Q52; Q58; O32

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 (*8*). Its predecessor, the "Two Control Zones" plan (TCZ)[2] piloted the idea of regional implementation of pollution control zones in 1998 (*21*). 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 incentive to develop more advanced and less polluting means of production. The increase in innovativeness of firms can compensate the spillover cost and therefore increase the competiveness. And innovation resulting from environmental regulations can make firms comparatively advantageous than foreign competitors. This theory is known as the Porter Hypothesis (*33*). This theory has been

[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), as well as 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 (*8*). The AQCZ policy includes provisions to reduce on SO_2 and NOx, as well as a comprehensive list of air pollution criteria including ozone, PM2.5 and others adopted from international clean air standards.

[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 which account for, in total, around 11.4% of China's territory (Hering and Poncet, 2014) (*16*). 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 (*20*). 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.

tested many times in developed countries (Nelson, 1994) (*25*), (Esty and Porter, 1998) (*11*), (Reinhardt, 1999) (*35*).

We thereupon delve into 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-Difference (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 former papers using pollution control expenditure (Jaffe and Palmer, 1997) (*18*), (Berman and Bui, 1999) (*6*), or timing of the introduction of environmental regulations (Popp, 2006) (*32*), our paper unprecedentedly compares patenting activities before and after the implementation of environmental policies. Apart from that, the policies we adopt are two different types. 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. What is more, these two policies cover different scopes of pollutant. This provides us good quasi-experiments to test how different types of environmental polices influence innovation.

We also consider the foreign equity ratio in each firm, since the Porter Hypothesis claims that domestic firms benefiting more from the policy than foreign competitors. This will provide us insight into the mechanism of the Porter Hypothesis. Additionally, we divide firms into different polluting levels. 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 to innovate. 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. In the third section, we analyze China's specific social and environmental background. The fourth and fifth sections provide model structures and data description. The sixth section, we do a series of robustness checks. The seventh section offers our conclusions and discusses some political implications.

Literature Review

The cornerstone of the theoretical part in our paper is based on Porter and van Linde (1995) (*33*), which suggests that properly designed environmental regulations can trigger innovation and that the innovation can in some cases exceed the costs of complying 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 (*18*)). 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 (*3*)). Most papers arguing for the "strong" form of the Porter Hypothesis have failed to confirm its existence (see: Alpay et al, 2002 (*2*); Gray and Shadbegian, 2003 (*36*); Crotty and Smith, 2008 (*39*); etc.).

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 resulting innovation ability. Jaffe and Palmer (1997) find whether the Porter Hypothesis exists or not depends on the measure of innovation used (*18*). Brunnermeier and Cohen (2003) (*7*) test how the numbers of environmental patents are influenced by pollution abatement expenditure (self-reported) and number of air and water pollution related inspections. They find the impact is significantly positive although showing small coefficients. Arimura et al. (2007) (*4*) 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.

There are also some papers examining whether the Porter Hypothesis exists in China. Yang and Yao (2012) (*44*) used certification of the ISO14000 as the environmental performance of firms and supports the "strong form" of the Porter Hypothesis, but using this self-regulated proxy failed to confirm the "weak form" of the Porter Hypothesis. Lin et al. (2014) (*22*) also sets strings of dummy environmental variables to test if firms' green product innovation and process innovation are affected by them. The results in their paper 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 adopt specific policies as indicators of environmental regulations. The methods used to test 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.

Empirical Model and Data

It is a common view that the Difference-In-Difference Model (DID) is efficient and convenient to analyze the influence of policies, especially with policies such as AQCZ or TCZ which vary with the time and regions, and involve two groups: experimental group and control group. There are no studies literally talking about how to use differential models to discuss the Porter Hypothesis. Nevertheless, a few studies such as JA List et al. (2003) (*23*), which uses the DID model to control the presence of unobservables in the research of environmental regulations in New York State, and R Hanna (2010) (*14*) using DID to research US-based multinationals. Both of these papers technically are testing the Porter Hypothesis in another way. Nevertheless, due to the specific target and goal of the environmental policies and regulations involved in our study, in this paper, 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 the R&D expenditures and patents will be explicated. The goal of this paper is to compare the before and after effects of these two policies with the placebo during the same period.

Difference-in-Difference-in-Difference Model Specification

The political background indicates that the whole Chinese cities were divided into two groups: one was under the environmental regulations and the other not. And 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 at two different time periods: one time period before "treatment" and one time period after "treatment". This condition actually satisfies the requirements of the Difference-in-Difference (DID) model, where $\bar{y_{11}} - \bar{y_{21}}$ represents horizontal difference between treatment group and control group before the regulations were launched; $\bar{y_{12}} - \bar{y_{22}}$ represents horizontal difference between the treatment group and control group after regulations implemented. $(\bar{y_{11}} - \bar{y_{21}}) - (\bar{y_{12}} - \bar{y_{22}})$ can be interpreted as the regulation effect. The DID model can be set as:

$$log(Pat)_{it} = \beta TCZ_i \cdot Time_t + \mu_t + \theta_i + X_{it}'\lambda + \varepsilon_{it} \tag{1}$$

with Two Control Zones policy or in Air Quality Control Zones policy:

$$log(Pat)_{it} = \beta AQCZ_i \cdot Time_t + \mu_t + \theta_i + X_{it}'\lambda + \varepsilon_{it} \tag{2}$$

$$log(R\&D)_{it} = \beta AQCZ_i \cdot Time_t + \mu_t + \theta_i + X_{it}'\lambda + \varepsilon_{it} \tag{3}$$

$TCZ_i = 1$ or $AQCZ_i = 1$ means the firm i is in the control zone and involved in the regulations. While $TCZ_i = 0$ or $AQCZ_i = 0$ means firm i isn't. $Time_i = 1$ means 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, like benchmark interest, GDP or any other macroeconomic factors. θ_i represents a certain firm $i's$ time-invariant features like production model, connections with local governments and so on. Apart from that, the DID model requires a parallel trend assumption. This means firms, no matter on the regulation lists or not, should have the same trend before the policy being conducted. Thus, another matrix X_{it} is added to supplement other factors that may influence the R&D expenditures or numbers of patents. Greek letters in the regression functions are the ones need estimating. Here, the R&D expenditures are already in the log form, so general OLS method is adopted to estimate coefficients. And as for the numbers of patents, they are discrete integers. WFW Yaacob et al. (2010) (*43*) mention that count data such as patents could be more accurately estimated by quasi-Poisson distribution or negative binominal distribution model.

Nevertheless, there are a few concerns with the DID model. First, presumably, the more polluting firms would be more heavily influenced by the regulations. In our data analysis, we discarded the finance-related firms as they are less relevant with production. But this still cannot solve estimation-biased problem, because the rest firms' polluting levels vary a lot. Second, we did control some time-invariant factors, while the time-varying factors were ignored, which may be correlated with the regressors and also bias the estimation. Additionally, not only can environmental regulations influence firms, but firms can exert influence on policy designs in some extent (see:Toke (1998) (*1*) and Nie & Huang (2013) (*34*)).

In light of these concerns, we take pollution intensity into account and adopt the Difference-in-Difference-in-Difference (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 explicated below:

$$log(Pat)_{itk} = \beta TCZ_i \cdot Time_t \cdot Pollution_k + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \tag{4}$$

with Two Control Zones policy or in Air Quality Control Zones policy:

$$log(Pat)_{itk} = \beta AQCZ_i \cdot Time_t \cdot Pollution_k + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \tag{5}$$

$$log(R\&D)_{itk} = \beta AQCZ_i \cdot Time_t \cdot Pollution_k + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \tag{6}$$

Where $Pollution_k$ added on 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. Here, we control province-year, year-industry and industry-province fixed effects. σ_{it} captures the province-year effects of a firm. We used province-year level, because firms in same province could show amount of common features like tax deductible, lowest salary requirement and etc. Also, in our later maximum likelihood estimation, too many dummies set can easily cause dispersion and result in a biased estimation. ω_{tk} represents year-industry fixed effects. We divided firms into 5 industry groups according to their register information in Shanghai Stock Exchange and Shenzhen Stock Exchange like real estate, public service and etc. ϕ_{ki} stands for industry-province fixed effects. By controlling industry-province effects, we allow industries vary across different provinces. This is unquestionably essential. Although power-centralized China often chooses to implement a policy across the country at the same time regardless of regional difference but it is the provincial government who chooses to implement the policy. Last, ε_{itk} is the error item.

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

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

$$log(Inv)_{itk} = \beta TCZ_i \cdot Time_t \cdot Pollution_k + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \tag{7}$$

$$log(Uti)_{itk} = \beta TCZ_i \cdot Time_t \cdot Pollution_k + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \tag{8}$$

$$log(Des)_{itk} = \beta TCZ_i \cdot Time_t \cdot Pollution_k + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \tag{9}$$

with Two Control Zones policy or in Air Quality Control Zones policy:

$$log(Inv)_{itk} = \beta AQCZ_i \cdot Time_t \cdot Pollution_k + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \tag{10}$$

$$log(Uti)_{itk} = \beta AQCZ_i \cdot Time_t \cdot Pollution_k + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \tag{11}$$

$$log(Des)_{itk} = \beta AQCZ_i \cdot Time_t \cdot Pollution_k + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \tag{12}$$

In these functions, Inv means invention, Uti means utility model and Des means design. In the DIDID model, the most important coefficient is the interaction coefficient β, which is the expression of the treatment effect. If cities in which firms selected into the regulation list are independent of variables in matrix X_{itk}, or expressed as $E(\varepsilon_{itk}|TCZ_i{\cdot}Time_t{\cdot}Pollution_k, X_{itk}) = 0$, we can get an unbiased estimation of the coefficient β. But in realistic political cases, we only require $\varepsilon'_{itk}s$ expectation is zero given the policy and can also get unbiased estimation.

As mentioned, there are two concerns. First, the number of patents are discrete. A proper way is to construct the 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 have a variance that's 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 (*41*). They often give similar regression results. Here, we just adopt the Quasi-Poisson regression.

We also investigate if well-experienced 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. Simpson and Bradford (1996) (*38*) and Greaker (2003) (*12*) both show that the domestic firms benefit from marginal costs reducing while the environmental regulations are the commitment device for them to invest in the R&D, then the domestic firms get more competitive in international markets comparing to the foreign ones. Due to the separation of ownership and management in modern corporations, the foreign equity ratio in every year is an important factor influencing daily operation (*37*). So, in order to find if foreign equity can influence the innovation abilities, each firm's foreign equity ratio in every year is considered as a part of the matrix. Other factors included is the asset of each firm, which represents the accumulated affects. And the age of the firm: the years since the firm was built up. Old firm can be considered as authentic in its field and with more experience.

Data description

I. Environmental Regulation Data

The measurement of environmental regulations comes from two detailed policies Chinese government implemented in 1998 and 2012 respectively. They are called the Two Control Zones and the Air Quality Control Zones, which mainly concentrated on the air pollution rather than others, but were introduced in with different backgrounds and purposes. The cities involved in these two policies are mapped in the appendix.

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

II. The Innovation Data

The R&D, patent and firms' asset, profit and stock equity data are derived from the CSMAR Database, which offers data on the China stock markets and 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. Apart from that, there are a few characteristics we are taking into account when processing the data. First, the financial enterprises are not in our consideration, since they are less relevant with production. Second, our datasets, both of the R&D and patents, are unbalanced. The time ranges of the tests of the two policies cover long periods. There are firms already existing before the starting years and some firms entered during the test periods. At last, it has to be noticed that the two policies are regional. In our models, whether a firm is influenced by the policy totally depends on its location. Thus, we drop all observations of firms whose production covers multiple regions such as utility companies or oil and gas enterprises.

II.1 The R&D 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 the R&D expenditures in the reports as well. Thus, the comprehensive R&D data of listed firms are available from 2010 to 2015, but here, only data after 2011 is collected since data in 2010 are too few. The capital often shows the log normal of distribution (DB Nelson, 1991 (*24*)). Obviously, the average expenditures soared after 2012, when the Air Quality Control Zones policy was introduced. This might hint the policy did impulse firms to devote more capital to the R&D behavior. Though with some fall in expenditure in 2013, the average expenditure exhibits some difference before and after the policy.

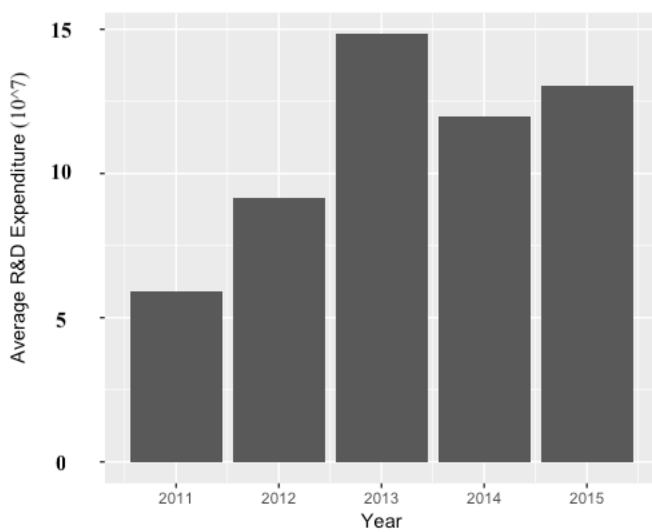

Figure 1: The average annual R&D expenditures of each firm

II.2 The Patent Data

The patent data of listed firms are available from 1994 to 2015. There is also the same problem as the R&D data and this problem was worse before 2000. 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. Utility model means any new solution relating to the shape, the structure or their combination, of a product, which 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 (*30*)[3].

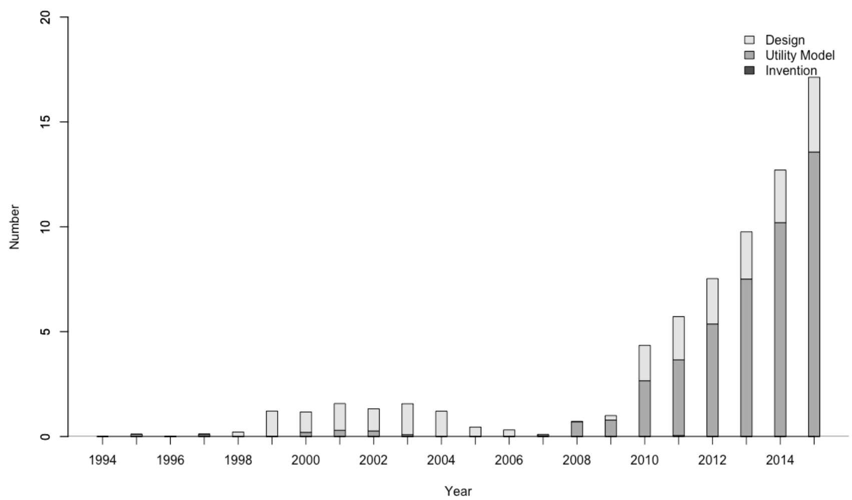

Figure 2: The annual average invention, utility model and design

As shown in figure 2, there are two peaks of the total number of patents: one emerged around the millennium time mainly due to the surging of design number; the other peak seems still in the development, beginning in 2009: the total number of patents has been soaring and hasn't reached its peak until 2015.

The numbers of utility model and design are far larger than invention. As mentioned in the last figure, in the average number of patents, the utility models account for most part of them. Moreover, the utility model is also the most fast-growing one as it is granted quickly and easily.

[3]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. There is no counterpart of utility model patent in the US.

A utility model usually receives preliminary examination but substantial examination is not required. A table is made to show the difference of protected matter, term, form of examination and relevant fees among three types of patents (*29*). The requirements in each step make the number of invention much less than utility model and design patent. It usually takes 1 to 1.5 years for the office to approve the invention application, and utility model or design only take less than 6 months (*10*). Thus, inventions are regard as the truly innovation.

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	2,500	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 1: Summary of three types of patents in China

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 the R&D expenditures. Both the TCZ and AQCZ policy are tested whether they had impacts on the number of patents of a firm.

I. The R&D Results

Table 2 shows the regression results of how the AQCZ policy influences the 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.

	R&D Expenditure					
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: *, ** and *** indicate, respectively, the significance level of 10%, 5% and 1%
From 2006-2015 for AQCZ

Table 2: DIDID Regression of R&D Expenditure Concerning AQCZ

From the regression results, the foreign equity in management coefficient also show a significant and positive sign. This suggests foreign equity also plays an important role in the R&D decision. The higher percent of foreign equity in management, the more probability that firms are willing to put more capital into the 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 that they are 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 the production or increase the production efficiency. Another famous phenomenon known to all is that China has strict capital flight control 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 research and develop center in China, which is usually high-cost and with few physical output. This could help foreign invested companies save a huge amount of tax cost or remit fee. Thus, only through R&D expenditures view, it is still hard to make a conclusion whether foreign firms are more environmental responsible or more easily being encouraged to develop new technologies under environmental restrictions.

II. The Patent Number Results

First, we test how the AQCZ policy influences total patent numbers and three sub-items. Table 3 presents no fixed effects controlled, only province-year effects controlled and three interaction terms controlled results. The test results with three effects controlled are in favor of the Porter Hypothesis again. Interaction coefficients are significantly positive no matter other possible factors are considered or not. In the data description part, we have already noticed that there was incredibly surge around year 2012. This, in some extent, support the regression results.

	Patents Number (Quasi-Poisson regression)					
AQCZ · Time · Pollution	0.8360*** (0.0545)	0.9517*** (0.0993)	0.7614*** (0.0998)	1.0246*** (0.1793)	0.2688** (0.1224)	0.5199** (0.2215)
Other Control Variables:						
Asset (log)	0.6335*** (0.0154)	—	0.6800*** (0.0134)	—	0.6880*** (0.0135)	—
Foreign Equity in Management	-0.1084 (0.1572)		0.0415 (0.1305)		-0.0411 (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: *, ** and *** indicate, respectively, the significance level of 10%, 5% and 1%
From 2006-2015 for AQCZ

Table 3: DIDID Regression of Patent Number Concerning AQCZ

However, we find that for the numbers of patents, foreign equity in management actually does not have any influence. The sign of foreign equity coefficients indeed show no significance levels. This result violates the derivative conclusion of the Porter Hypothesis again. But actually several empirical research find the characteristics of a firm's capital structure has no impacts on its environmental or pollution disposal. Tang (2009) used Corporate Social Responsibility (CSR) to measure several social responsibilities of Chinese domestic companies and global companies, including environmental responsivity, but only find that there is no significant difference in their emphasis on environmental conservation (*40*).

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

	Patents Number (Quasi-Poisson regression)					
	Invention		Utility Model		Design	
AQCZ · Time · Pollution	-0.0154 (0.0102)	-0.0150 (0.0100)	0.6076*** (0.1270)	0.9073*** (0.2586)	-0.4626*** (0.1300)	-0.3767** (0.1648)
Other Control Variables:						
Asset (log)	0.0024* (0.0014)	—	0.7095*** (0.0127)	—	0.4490*** (0.0184)	—
Foreign Equity in Management	0.0157 (0.0106)		-0.2977** (0.1208)		0.5864*** (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: *, ** and *** indicate, respectively, the significance level of 10%, 5% and 1%
From 2006-2015 for AQCZ

Table 4: DIDID Regression of Sub-items Number Concerning AQCZ

First, utility model shows similar results with total patents, because what we know is that after 2010, utility model accounts for nearly 70 to 80 percent of total patents. So there is no surprise that AQCZ policy exerts significant and positive effects on the numbers of utility model. But it shows foreign equity makes negative effects on the utility numbers. This means firms with higher ratio of foreign equity are not willing to develop low quality innovation. Then, an interesting finding is that inventions are neither promoted nor impeded by the environmental regulations, nor was inventions influenced by the ratio of foreign equity in a firm's management. Utility model is often called “Invention Lite as it shows similar purpose as invention but with much lower standards or requirements. Thus, when confronting the strict regulations, firms may rather 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 the productivity when there is a target set for emissions. When it comes to design, we found regression results indicates the number of designs being significantly and negatively influenced by the environmental regulations. Actually, design patents only focus on the appearance of a product rather than the quality or efficiency. If under the limited budget and strict environmental regulations, pragmatic firms definitely would rather choose to put more weight on utility models, which is consistent of our intuition. When refer to the foreign equity ratio in management, it shows foreign equity promoted the creation of design.

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

	Patents Number (Quasi-Poisson regression)					
TCZ · Time · Pollution	-0.0597 (0.1353)	0.2422* (0.1414)	-0.0598 (0.1248)	-0.0597 (0.1353)	-0.3156** (0.1444)	-0.2834* (0.1551)
Other Control Variables:						
Asset (log)	0.2306*** (0.0431)	—	0.2470*** (0.03448)	—	0.2636*** (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: *, ** and *** indicate, respectively, the significance level of 10%, 5% and 1%
From 1995-2005 for TCZ

Table 5: DIDID Regression of Patent Number Concerning TCZ

The results shown above may have two possible reasons. First, as mentioned in 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 great target, is one thing, but whether it was implemented strictly is another matter. So, if the policy was not implemented in a proper way, it already violates the prerequisite of the Porter Hypothesis. Second, it is also possible that the Porter Hypothesis does not work in that period's macroeconomic background. Next, we look at detail of how patents sub-items are influenced by the TCZ policy.

	Patents Number (Quasi-Poisson regression)					
	Invention		Utility Model		Design	
TCZ · Time · Pollution	0.0000*** (0.0000)	0.0000 (0.0000)	-0.0627 (0.0453)	-0.0543 (0.0473)	-0.3032** (0.1480)	-0.2718* (0.1579)
Other Control Variable:						
Asset (log)	0.0000*** (0.0000)	—	0.0751*** (0.0123)	—	0.2439*** (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: *, ** and *** indicate, respectively, the significance level of 10%, 5% and 1%
From 1995-2005 for TCZ

Table 6: DIDID Regression of Sub-items Number Concerning TCZ

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

III. The Mechanism Triggering Innovativeness

We have derived the conclusions from our previous analysis that well-designed environmental regulations could simulate innovativeness. It is necessary to delve into the potential mechanisms behind. There are a few theories about mechanisms triggering the innovativeness such as policy simulating industry-generated information, reducing long-term uncertainties and providing flexibility (V Norberg-Bohm, 1999 (*27*)). But there are studies notice that a freely competitive market is hard to spark innovation (Nelson, 1959 (*26*); Arrow, 1962 (*5*)). Thus, intellectual property protection, subsidies, tax incentives and etc. from the government are important to prompt firms follow the rules. When facing regulations, firms tend to finance innovation activities internally and Opler and Titman (1994) (*31*) 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 (*13*). Thus, in this part, we are going to test whether the favorable environmental regulation forces firms to set fluid assets to innovate. We consider the profit ratio, which is measured by fraction of annual profit to asset. The higher this ratio being, the more fluid funds a firm has for innovation activities.

$$log(R\&D)_{itk} = \beta(AQCZ_i \cdot Time_t \cdot Pollution_k) \cdot RoP_{itk} + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \quad (13)$$

$$log(Pat)_{itk} = \beta(AQCZ_i \cdot Time_t \cdot Pollution_k) \cdot RoP_{itk} + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \quad (14)$$

$$log(Inv)_{itk} = \beta(AQCZ_i \cdot Time_t \cdot Pollution_k) \cdot RoP_{itk} + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \quad (15)$$

$$log(Uti)_{itk} = \beta(AQCZ_i \cdot Time_t \cdot Pollution_k) \cdot RoP_{itk} + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \quad (16)$$

$$log(Des)_{itk} = \beta(AQCZ_i \cdot Time_t \cdot Pollution_k) \cdot RoP_{itk} + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \quad (17)$$

Where RoP_{itk} stands for the profit ratio. We set it as a term in the interaction term. This makes our models possible to reflect the change of fluid funds a firm holds. We test both R&D expenditures, the total number of patents and sub-items. And the results are shown below.

	R&D Expenditure	Patents Number	Invention	Utility Model	Design
(AQCZ · Time · Pollution) · RoP	0.5491*** (0.0659)	3.9342*** (0.3104)	-0.0227 (0.0353)	3.8297*** (0.2967)	3.36508*** (0.4238)
Other Control Variables:					
Asset (log)	0.6713*** (0.0129)	0.7095*** (0.0130)	0.0023 (0.0014)	0.7336*** (0.0122)	0.4589*** (0.0183)
Foreign Equity in Management	0.4596*** (0.0906)	-0.1745 (0.12396)	0.0165 (0.0106)	-0.4306*** (0.1167)	0.4314*** (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: *, ** and *** indicate, respectively, the significance level of 10%, 5% and 1%
From 2006-2015 for AQCZ

Table 7: DIDID Regression testing the mechanism

The results from the table above display same significant levels and signs as previous ones when we have all three fixed effects controlled. This means it is more possible that the policy first affects firms' cash flow, making firms set more internal funds to innovate. Chinese economic background could further affirm this assumption since state-owned banks are more unwilling to lend money to innovation activities. Apart from that, we introduce another dataset[4]. It collects all individual patent information including the applicants, International Patent Classification Codes etc. First, we adopt the standards of the OECD (*15*) (*28*) to define green patents to classify our patent dataset according to International Patent Classification Codes. Nevertheless, in our dataset from year 1998 to 2016, covering over 25800 patent, green patents only number 136, which accounts for only 0.5% of the total. This finding suggests that firms tend to develop patents relevant with productivity rather than combating pollution.

[4]The dataset was derived from SIPO (State Intellectual Property Office of the P.R.C)

Robustness Check

In the research of the impacts of the policies, we concern the endogeneity problems existing which may lead to biased estimation. Our DIDID model solves the likelihood of policy dummy variables 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 placebo test.

I. 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, though there are same standards. According to Hübler et. al. (2014) (*17*), in China, different GDP level areas and different sectors have different efficiency in conducting environmental policies. Considering this, we need to distinguish to which extent a firm is influenced by a certain policy. Here, referring to J Wu et al. (2013) (*42*), we use the fraction of expenditure province government spent on combating air pollution to the total annual budget as the indicator for policy stringency. So, we just use the new item $AQCZ^{str}$, which reflects the regulation stringency a firm confronted, to replace the previous dummy variable. the $AQCZ^{str}$ is 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 this fraction might vary across provinces. The province level government has more power to determine the annual targets for pollution control. Then we can construct our new model considering the policy stringency.

$$log(Pat)_{itk} = \beta AQCZ_i^{str} \cdot Time_t \cdot Pollution_k + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \tag{18}$$

$$log(R\&D)_{itk} = \beta AQCZ_i^{str} \cdot Time_t \cdot Pollution_k + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \tag{19}$$

Here, we test the AQCZ policy and get our results:

	Patents Number (Quasi-Poisson regression)					
AQCZ_str · Time · Pollution	0.3189*** (0.0312)	0.3322*** (0.0604)	0.6396*** (0.0901)	0.5874*** (0.1382)	0.2219** (0.1017)	0.3087** (0.1493)
Other Control Variables:						
Asset (log)	0.6393*** (0.0165)	—	0.6898*** (0.0133)	—	0.6924*** (0.0135)	—
Foreign Equity in Management	0.0420 (0.1674)		0.0979 (0.1297)		-0.0219 (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: *, ** and *** indicate, respectively, the significance level of 10%, 5% and 1%
From 2006-2015 for AQCZ

Table 8: DIDID Regression of Patent Number Concerning the AQCZ stringency

	R&D Expenditure					
AQCZ_str · Time · Pollution	0.1090*** (0.0176)	0.1606*** (0.0196)	0.3022*** (0.0346)	0.3829*** (0.0388)	0.3395*** (0.0471)	0.3520*** (0.0549)
Other Control Variables:						
Asset (log)	0.6356*** (0.0134)	—	0.6412*** (0.0131)	—	0.6715*** (0.0129)	—
Foreign Equity in Management	0.4338*** (0.0966)		0.3759*** (0.0938)		0.4605*** (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: *, ** and *** indicate, respectively, the significance level of 10%, 5% and 1%
From 2006-2015 for AQCZ

Table 9: DIDID Regression of R&D Expenditure Concerning the AQCZ stringency

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

II. 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 released, some firms might get information and prepare for it in advance. Second, the introduction of AQCZ policy might have sustained effects and it also costs firms a period of time for them to improve the innovation ability. Hence, it is necessary take lags and leads terms into account in our model. Following Laporte and Windmeijer (2005) (*19*), the DIDID model with lags and leads terms are explicated below:

$$log(Pat)_{itk} = \sum_{t=-2}^{2} \beta_{2012+t} AQCZ_i \times Time_{2012+t} \times Pollution_k + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \quad (20)$$

$$log(R\&D)_{itk} = \sum_{t=-2}^{2} \beta_{2012+t} AQCZ_i \times Time_{2012+t} \times Pollution_k + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \quad (21)$$

Where $Time_{2012+t}$ is the indicator for year $2012 + t$. We set two years forward and two years backward with default year 2012. So that coefficients β_{2012+t} captures two years lag to two years lead effects. We plot the results of coefficients.

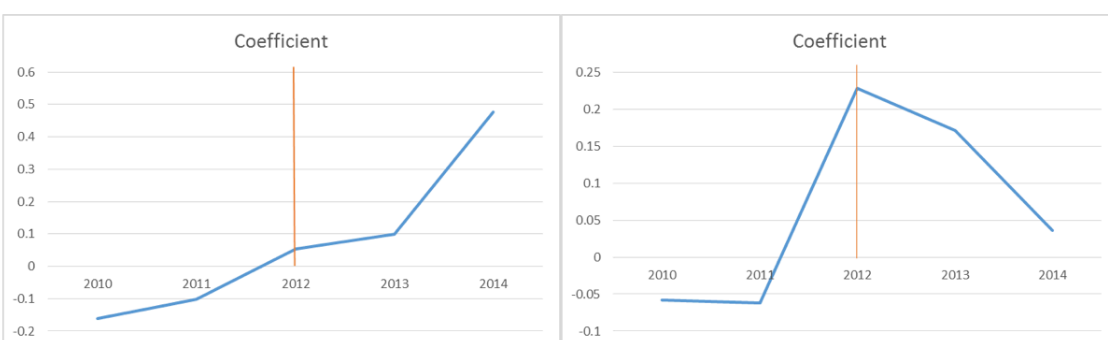

Figure 3: Time Changing Coefficients (Left: R&D Expenditures, Right: Patents Number)

From the figures above, no matter R&D expenditures or patents number, we can notice that there are no leads effects of 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 suddenly increase to positive. And the coefficients in the time changing DIDID models are very similar with the original models in default year. This means only after the policy released, firms started to realize the importance of environmental innovation. This reflects a common phenomenon in China that, before the AQCZ policy, policies are often a slogan rather than real implementation. However, AQCZ policy seems different from former 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 AQCZ policy is immediate. A divergence in trend occurs after 2012 between R&D expenditures and number of patents. Although it is still positive of the AQCZ policy coefficients, AQCZ policy exerts larger and larger influence on R&D expenditures with contrary effects trend on the number of patents.

III. Placebo Test

In order to make our finding more solid, we decide to make a test to see if the AQCZ policy is the key factor that lead to the increase of the R&D expenditures or the number of patents. Thus, we conducted the placebo test according to same method provided by Chetty et al. (2009) (*9*). In our data sample, there are 3198 listed firms in total and 2468 firms or 77.18% are involved in the AQCZ policy. Then, we stochastically set 77.18% of the total firms as the AQCZ policy influencing ones, in other words, whose dummy variable for AQCZ policy equals 1. And the rest are set as 0 valued dummy variable. This step eliminates the effects of the AQCZ policy. We rule out incomplete samples in different regression models.

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

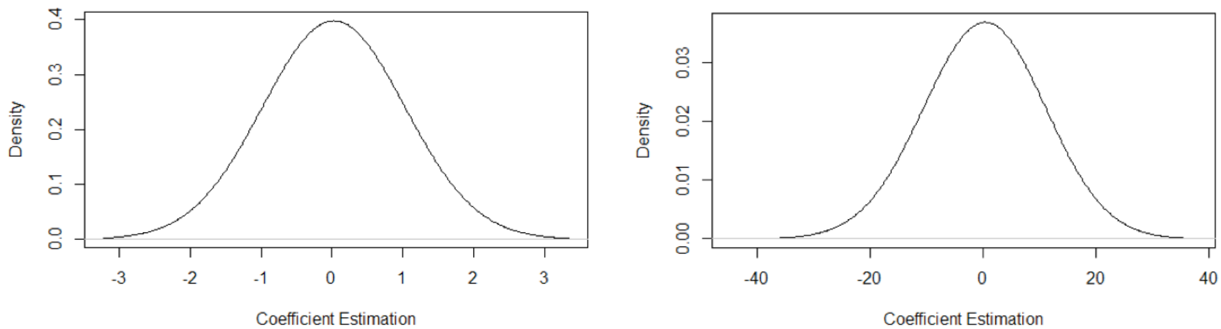

Figure 4: Distribution of Coefficient Estimation Density (Left: R&D Expenditures, Right: Patents Number)

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

Conclusion

This paper considers two recent Chinese pollution control regulations, the TCZ policy in 1998 and the AQCZ policy in 2012, to test whether the Porter Hypothesis holds in China. The impact of the two policies in our study is identified by the comparison of the outcome variable for the AQCZ/TCZ cities in intensively polluting industries vis-à-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 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 low-quality patents mostly, while TCZ reduced the number of patents across the board with a comparatively more negative impact on the low-quality patents that 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.

This paper complements existing research about the Porter Hypothesis and introduces several novel elements to this line of inquiry. Firstly, most existing studies concerning the Porter Hypothesis are based on U.S. or European data. Secondly, we introduce the concept of DIDID method to Porter Hypothesis and innovation research by selecting our datasets and structuring the outcome data around the two policies in a way that enables multiple layers of examination of the differences, allowing us to isolate the polluting from the non-polluting, and the before implementation from the after. During our regression analysis, we try to further solve the endogeneity problems correlated with biased estimation. And due to the limit of green patents in China, we cannot further explore the development of ecotechnology. But the burgeoning of awareness of the environment in China provides us the vision to discuss this topic in near future. Though we do not resolve the endogeneity and other concerns entirely, we believe our paper makes an important methodological contribution research in the area of environmental policy and innovation.

Appendix

Figure 5: Two Control Zones (TCZ) Policy Area, 1998

Figure 6: Air Quality Control Zones (AQCZ) Policy Area, 2012

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