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, strategists, environmentalists, and policymakers alike over the past 25 years posits that well-designed environmental regulation can induce efficiency and innovation in competitive industries. 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 a control, offers researchers the perfect conditions for a natural experiment. We use the Difference-In-Difference-In-Difference (DIDID) method to test if the Porter Hypothesis is

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supported by the recent regulatory efforts in China. Using R&D expenditures and number of patents granted to measure innovation, we compare the record of innovation of firms inside the policy zones with firms outside the policy zones. Using a novel Chinese patent data set, we also take the sub-items of patents into account, considering not just raw patent count but the quality and originality of the patents, which is rated at the time of issue in China (invention, utility model and design). Considering these results in the context of the foreign equity ratio in ownership, we are able to explore the role foreign equity plays in firms' innovation ability. Results show only one of the regulations had a significantly positive effect on firms' innovation, and that low quality (utility model) patents accounted for most of the innovation. We also find that the percentage of foreign equity had no correlation with the overall number of patents or with most of patent sub-items, but that increased foreign equity did increase R&D expenditure. In our robustness checks, we consider the possibility that biased estimation due to the high number of firms with zero patents, using instrumental variable with two stages regressions, lags and leads effects of policy and a placebo test. The robustness checks 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; China

Introduction

Air pollution in China has become a major topic of concern for both foreign observers and the Chinese government in recent years. In the last decade, China accounted for over 2/3 of total global carbon dioxide emission growth (*36*). In 2015, China was ranked as the top emitter of carbon dioxide, making up 30% of total emission, double the CO2 emissions of the next highest, the United States (*12*). Zhang and Cao (2015) (*43*) found that only 25 out of 190 cities met the National Ambient Air Quality Standards of China, and the mean annual exposure (PM2.5) in Chinese cities is $61\mu g/m^3$, around three times as high as the global level. At the same time, there are also increasing signs that the Chinese government is taking the problem seriously and devoting substantial resources to addressing it. In 2015, China invested more than $100 billion or 36% of the world total expenditures in clean energy, up from $89.5 billion last year, more than double the USA investment ($44.1 billion) (*11*) (*18*) (*26*). China has also directed significant resources into the clean energy sector. In 2016, China was the biggest producer of solar energy (77.42 gigawatts) (*34*), hydropower (1189.48 TWh) (*5*) and wind energy (149 gigawatt) (*39*).

In parallel with these investments in a more alternative energy-driven future, the Chinese government has been moving forward with more aggressive, and more controversial, Western-style regulation to rein in the polluting industries already in operation and to limit their growth going forward. China formally joined the Paris Agreement in October 2016. In January 2017, the Chinese government canceled the construction of more than 100 coal-fired power plants, representing 120 GW of capacity (around equivalent to 1/3 of the existing USA coal fleet) (*26*). China set a target for the year 2030 that renewable energy could cover 26.7% of China's total consumption (*32*). 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 (*7*). Its predecessor, the Two Control Zone plan (TCZ) piloted the idea of regional implementation of pollution control zones in 1998 (*23*). 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: will these regulations impair the labor-intensive Chinese industries and impede their economic development?

[1] the full name of AQCZ is "Twelfth Five-Year Plan on Air Pollution Prevention and Control in Key Regions"

In this paper, by researching two air quality-related environmental policies, we explore how firms in China are 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 innovation of firms can compensate the spillover cost and therefore increase the competiveness. And innovation resulting from environmental regulations can make firms more comparatively advantageous than foreign competitors. This theory is known as the Porter Hypothesis (*30*). This theory has been tested many times in developed countries (Nelson, 1994) (*25*), (Esty and Porter, 1998) (*13*), (Reinhardt, 1999) (*33*).

We would like to see if relevant 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: the Two Control Zones policy in 1998 and the Air Quality Control Zone policy in 2012. We use 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 innovation. Our research method is a comparatively more precise paradigm to test the Porter Hypothesis for the following reasons. First, we consider two specific policies. This is more consistent with the policy requirements put forward by the Porter Hypothesis itself. Compared with former papers which used pollution control expenditure (Jaffe and Palmer, 1997) (*19*), (Berman and Bui, 1999) (*4*), or timing of the introduction of environmental regulations (Popp, 2006) (*29*), our paper unprecedentedly compares patenting activity before and after the implementation of environmental policies.

The policies we adopt are two different types. TCZ policy is more of a pilot or trial stage policy, which means the government set a general goal or target and left it to the local government who implement these policies according to their own standards. What is more, TCZ focuses only on SO_2 or NOx source like coal mining and coal-fired power plants. AQCZ, on the contrary, is a more centralized policy, which is conducted according to a battery of the same standards. 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. The Porter Hypothesis is in favor of domestic firms benefiting more from the policy than foreign competitors under the regulations. We will see to what extent foreign capital influences firms' R&D expenditure and the number of patents as well as the patent sub-items. This will provide us insight into the mechanism of the Porter Hypothesis. Additionally, we divide firms into polluting sector and less polluting sector. The Porter Hypothesis' original edition is a case study and including later relevant empirical articles, it focuses 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 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. In the seventh and final section we offer our conclusions and discuss the political implications.

Literature Review

Porter and van Linde (1995) (*30*) 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 the environmental regulation (Jaffe and Palmer, 1997 (*19*)). This form, which is closest to Porter's original 1995 formulation in that it acknowledges the inherent tensions, has been met with gradual but lasting acceptance by economists and policymakers. 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 (*2*)]). Most papers arguing for the strong form of the Porter Hypothesis have failed to confirm its existence (see: Alpay et al, 2002; Gray and Shadbegian, 2003; Crotty and Smith, 2008; etc.).

Our paper's purpose is mainly to confirm whether environmental regulations in China indeed booster firms' innovation ability. Thus, we actually only focus on 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) found whether the Porter Hypothesis exists or not depends on the measure of innovation used (*19*). Brunnermeier and Cohen (2003) (*6*) tested how the numbers of environmental patents are influenced by pollution abatement expenditure (self-reported) and number of air and water pollution related inspections. They found the impact is significantly positive although showing small coefficients. But this paper also points out that the proxies cannot fully stand for the stringency of environmental regulations as there are many other factors influence these two proxies and firms often overstate the environmental expenditures. Arimura et al. (2007) (*3*) 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) (*42*) 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) (*24*) 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 shows that national specific environmental regulation for an industry exerts significantly positive effects on firms' green product or process innovation.

The papers mentioned above all adopt general panel data regression model. However, because we seek to understand the impact of two specific environmental policies, it would be both more intuitive and more precise to use Difference-In-Difference model. Difference-In-Difference-In-Difference model creates another difference according to a specific dimension other than the implementation of a policy (e. g. Jonathan Gruber (1994) (*15*) uses DIDID to research the effect of insurance mandates for maternity coverage on male and female wages; Jane Waldfogel (1999) (*41*) uses DIDID to research how Family and Medical Leave Act affects different age and gender groups; Xiqian Cai et al. (2016) (*8*) uses DIDID to research how TCZ policy influences the inbound FDI considering different polluting level in various cities. When it comes to a specific policy, one of most important problems we confront is endogeneity in the regression model and no matter the DID model or DIDID model, both are put forward in order to solve the potential endogeneity (see Hanna (2011) (*16*)).

In our paper, we integrate the methods and ideas of above papers and use DIDID model to research two specific Chinese environmental policies. The first and second difference in our DIDID model come from whether a metro area falls within the zone of environmental regulations and whether the environmental regulations are implemented, which are the same as the general DID model. The third difference comes from the characteristics of different industries, in this case divided into polluting and non-polluting for reasons we will explain in the next section.

Background

Two Control Zones (TCZ)

The full name of the Two Control Zones policy is Acid Rain Control Zones and Sulfur Dioxide Pollution Control Zones, (the two things to be measured and controlled were acid rain and sulfur dioxide). The areas covered were the urban-industrial centers where acid rain stemming from air pollution was becoming an increasingly serious problem. By the mid-1990s, the acid rain area in China had reached more than 1 million kilometers (*23*). The area where precipitation with annual average PH less than 5.6 had come to cover 40% of total China territory, concentrated in the industrial south and center of China where much of the population lives (*44*). Heavily dependent on coal for electricity and needing to burn ever more to keep up the rapid pace of industrialization and urbanization, the subsequent increases in SO_2 and NOx emission caused extensive acid rain in these areas, badly damaging forests, crops, and human health (*22*). By the late 1990's, acid rain in China was no longer an ignorable problem.

In 1998, the Chinese State Council approved the Scenario for the Delineation of Acid Rain and SO_2 Pollution Control Zones (also known as TCZ). Beginning in 1999, the State Environmental Protection Administration of China began to conduct the TCZ policy. 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. The figure 1 shows the cities involved in the TCZ policy and table in Appendix 1 provides a list by province.

The Two Control Zone policy covered 1.09 million square kilometers, comprising 175 cities in 27 provinces which account for, in total, around 11.4% of China's territory. According to 1996 State Department of China's report and ninth Five-Year plan, TCZ policy set up two checkpoints for SO_2 control: 2000 and 2010. The policy stipulated that by 2000, the total SO2

Figure 1: Two Control Zones (TCZ) Policy Area, 1998

emission should be equivalent to or lower than 1995 levels and that the SO_2 concentration in major cities should be under national standard. In 2010, the total SO_2 emission should be 10% lower than 1995 and all cities should satisfy the national standard of SO_2 concentration. The acid rain area (PH of precipitation lower than 4.5) should shrink accordingly.

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 (*21*). Several specific measures were adopted to limit the SO_2 emission from coal-burning activities.[2]

[2]First, coal mines with over 3% sulfur were prohibited from operating altogether. Already-built mines with sulfur over 3% were ordered to close before 2000. Coal mines with sulfur over 1.5%, whether already built or ready to be built, were ordered to be equipped with coal preparation instruments. For these built mines with sulfur over 2% in seam must supplement coal washing equipment before 2005. Second, for the coal transportation, the TCZ policy involved area would be strictly monitored. The transportation department would guarantee low-sulfur coal and clean coal first be transported to TCZ policy-area cities. Firms in TCZ area were forbidden to import fuel oil with sulfur concentration larger than 2% or coal with sulfur concentration larger than 1%. Third, new coal-fired

In summary, the total SO_2 emission in TCZ cities accounted for 40% of all over the country emissions in 1998. The TCZ stipulated that by 2000, SO_2 emission should be reduced by 2.2 million tons and by 2010 reduced by an additional 5.6 million tons.

Air Quality Control Zones (AQCZ)

On December 5, 2012, Ministry of Environmental Protection (MEP), National Development and Reform Commission (NDRC), and Ministry of Finance jointly issued 12th Five-Year Plan on Air Pollution Prevention and Control in Key Regions. Hereafter, this long-name will be simplified as Air Quality Control Zones (AQCZ). It was set up amid rising awareness of the harm that air pollution was causing and the suspicion that it had increased substantially in recent years. 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 (*7*).

The AQCZ policy like its predecossor includes provisions to reduce on SO_2 and NOx, unlike the TCZ, however, it also includes a comprehensive list of air pollution criteria including ozone, PM2.5 and others adopted from international clean air standards. According to Clean Air Alliance of China's 2015 annual report, until 2010, the total SO2 emission in TCZ policy involved area decreased 14.29%. AQCZ can be regard as a successor to TCZ, one that focuses more on overall air quality where TCZ focused more narrowly on preventing acid rain. In 2010, the emission of SO2 and NOx in China both exceeded 20 million tons and smoke and dust emission are over 14 million tons. They all far exceed the carrying ability of environment. The

power plants would not be allowed to be built in major cities. Power plants which used coal containing sulfur concentration larger than 1% would be mandated to take measures to desulfurize before burning. For firms in TCZ policy involved area, sewage charges would be required for discharges over the emission limits.

Figure 2: Figure 2. Air Quality Control Zones (AQCZ) Policy Area, 2012

AQCZ area, as mentioned, although small in relative land area, accounts for 48% CO2 emission, 51% NOx emission, 42% smoke and dust emission and 50% VOCs. The strength of pollution emissions in these areas are 2.9 to 3.6 times higher than left areas. [3]

[3]The target of AQCZ is to reduce inhalable matter by 10%, SO_2 by 10%, NO_2 by 7%, fine particulate matter by 5% before 2015. The AQCZ policy put forward more rules and targeted more pollutants. First, high energy-consumption and high polluting programs are closely supervised. Coal-fired power plants are not allowed to be built in most of cases. High polluting projects in iron, steel, cement, petrochemical, non-ferrous, building materials and coking industries will not be approved. Production certification will not be issued and water, electricity will not be supplied if these projects have not passed the evaluations.

In the AQCZ area, low efficient and out of date thermal power, steel, building material projects are forced to update or close according to China's 2011 new Backward Production Technologies Instruction Menu. In order to substitute coal-fired power plants, different sustainable energies are encouraged to develop according to various geological characteristics like wind energy, solar energy, biomass briquette, shale gas and etc. Local governments are required to increase the fiscal and tax supporting. In the contrary, no-burning zone for heavy polluting fuel like coal or heavy-oil in AQCZ cities should cover at least 80% areas.

As for acid gas like SO_2 or NOx, not only power plants are required to reduce the emission, but also factories equipped with coal-fired units should improve the Selective Catalytic Reduction with efficiency at least over 85%. As for industrial smoke and dust, in AQCZ area, the upper limit is $20mg/m^3$. If coal-fired units cannot satisfy this

Compared with TCZ policy, the AQCZ policy put more weight on individual firms' production and more pollutants were taken into account. What is more, AQCZ policy referred former environmental policies during big events hold in China. The common characteristic of those policies is all cities involved adopt the same standards to process pollution, which is also different from TCZ policy that it is the local government takes different measures according to its own conditions.

Empirical Model and Data

It is a common view that Difference-In-Difference Model (DID) is an efficient and convenient way to analyze the influence of policies. Especially with policies like AQCZ or TCZ which vary with the time and regions and result in two groups: experimental group and control group. But due to the specific target and goal of the environmental policies and regulations, in this paper, we make one more difference. Both in two groups, there are before and after policy observations. Then, the panel data of R&D expenditures and number of patents will be explicated. The goal of this paper is to compare the before and after effect of these two policies with the placebo during the same period.

Difference-in-Difference-in-Difference Model Specification

The political background shows us that the whole Chinese cities are 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 just makes our dataset 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 requirements of the Difference-in-Difference

standards sustainably, renovation of disposal of smoke and dust should be adopted.

(DID) model, where $\bar{y_{11}} - \bar{y_{21}}$ represents horizontal difference between treatment group and control group before regulations were launched; $\bar{y_{12}} - \bar{y_{22}}$ represents horizontal difference between treatment group and control group after regulations. $(\bar{y_{11}} - \bar{y_{21}}) - (\bar{y_{12}} - \bar{y_{22}})$ then can be interpreted as the regulation effect. The 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 the 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 will be estimated then. Here, 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. From the data introduction part, we learnt that they are usually quasi-Poisson distribution or negative binominal distribution.

Nevertheless, here comes concerns with the DID model. First, presumably, the more polluting firms would be more heavily influenced by the regulations. In the data analysis, we discarded the finance-related firms as there is nothing with them about production. But this still cannot solve estimation-bias 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. What is more, not only can environmental regulations influence firms, but firms can exert influence on policies making in some extent (see:Toke (1998) (*1*) and Nie & Huang (2013) (*31*)).

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 as 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 it is a heavy polluting industry, while $Pollution_k = 0$ indexes a less polluting one. We distinguish different pollution level industries according to the Chinese classification of industries: agriculture, industry and service. As it is showed in the appendix, the agriculture and industry departments are more tend to be 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 first same province firms 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 important. Although power-centralized China often chooses to implement a policy across the country at the same time regardless of the 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 make a difference again based on previous DID 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 regulation effects on polluting firms compared to less polluting ones.

Then, with a series of sub-items of patents model set to research how environmental regulations influence different innovation level patents, 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 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 problems. 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, usually there is little probability that the mean and variance of numbers of patents happen to be same. The distribution of 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 (*40*). They often give similar regression results. Here, we just adopt the Quasi-Poisson regression.

It's also interesting to figure out if well-experienced foreign companies or foreign capital invested companies will behave better in innovation abilities, because if so, foreign companies or foreign equity invested companies may prevail under such environmental regulations. There might be probability that domestic firms behave better, which is just consistent with the Porter Hypothesis' derivative conclusion. 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, in the log form, which represents the accumulated affects. Obviously, the more asset a firm owns, the larger possibility that it will invest more on research and development activities as well as the higher outcome of patents. And then 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 in new products developing. Usually the earlier a firm established, the earlier it will go market. That may exert some benefits for the firm to raise money and then the expand R&D investment.

The derivative research of the Porter hypothesis shows that domestic firms benefit more from environmental regulations. Simpson and Bradford (1996) (*37*) and Greaker (2003) (*14*) both showed that the domestic firms will benefit from marginal costs reducing while the environmental regulations are the commitment device for them to invest in 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 in management is considered as an important reason influencing daily operation and nfluencing the innovation (*35*).

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. These two policies mainly concentrated on the air pollution rather than others, while they were introduced with different backgrounds and with different purposes. The cities involved in these two policies are listed on the appendix and the data was gotten from government reports or websites.

As we use the Difference-in-Difference-in-Difference method to make regression, 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 and showed on the appendix.

II. The Innovation Data

The R&D, patent and firms asset, profit and stock equity come from CSMAR Database, which offers data on the China stock markets and the financial statements of Chinese listed companies. Most of enterprises level data comes from this database. Due to the limitation of data collection, only after 2010, the R&D data is available. Thus R&D expenditure is testable for the Air Quality Control Zones rather than the Two Control Zones.

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 R&D expenditures in the reports as well. Thus, the comparative comprehensive R&D data of listed firms is available from 2010 to 2015, but here, only data after 2011 is collected since data in 2010 are too few. First, the distribution of R&D expenditure and its log form is showed below:

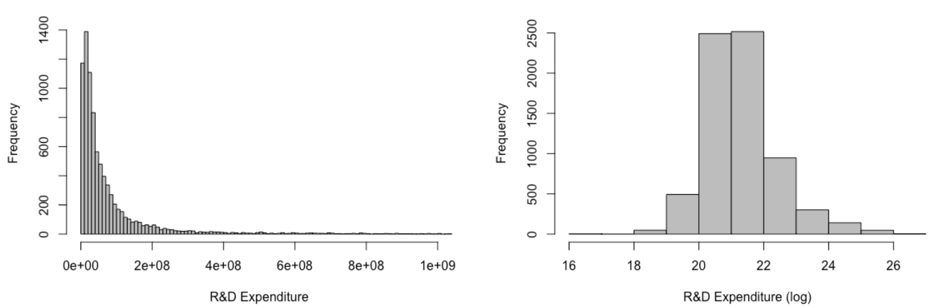

Figure 3: The distribution of R&D Expenditure and its log form

The capital often shows the log normal of distribution, which is clear from the right part of figure above. The distribution of R&D clusters is in the left side. The frequency slashing with the expenditure amount increasing and leaves a long tail. While the log form distributes evenly in each side. Then the average of R&D expenditure of each firm is showed below:

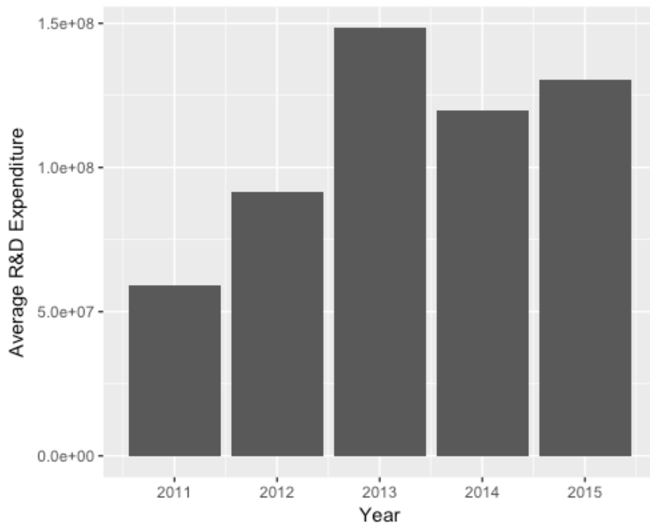

Figure 4: The average annual R&D expenditures of each firm

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.

II.2 The Patent Data

The patent data of listed firms is available from 1994 to 2015. There is also the same problem with the R&D data and this problem was worse before 2000. Chinese patents can be categorized into three types: Invention, Utility Model and Design. And in the dataset, the financial enterprises are taken from it.

According to the explanation of the State Intellectual Property of China, invention means any new technical solution 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 (*28*). 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.

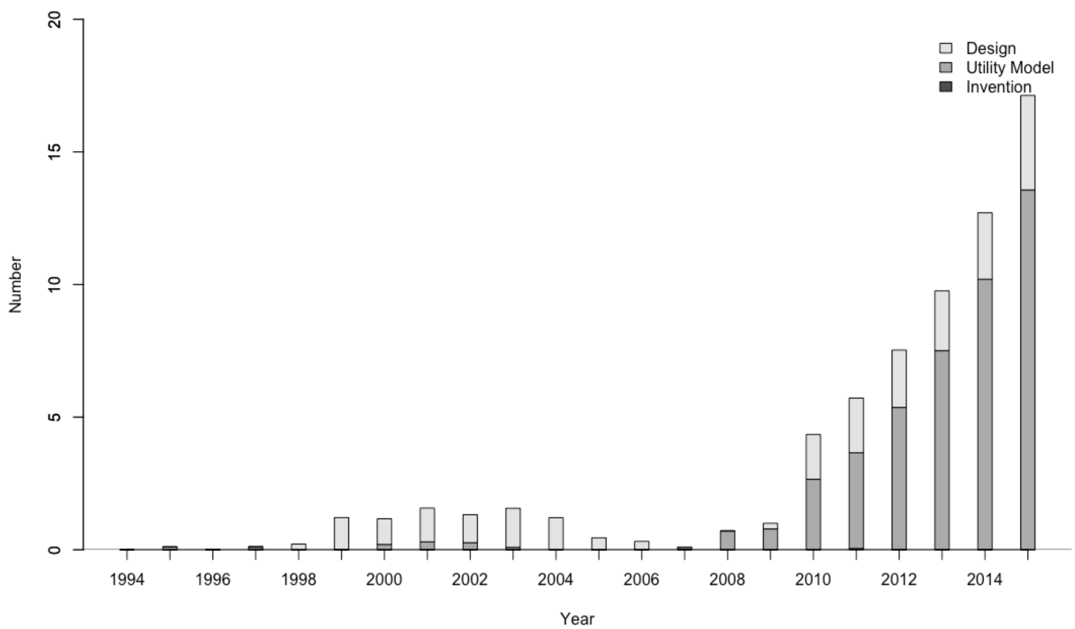

Figure 5: The annual average invention, utility model and design

As shown in the figure above, 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 hasnt reached its peak until 2015.

The numbers of utility model and design are definitely larger than invention[4]. As mentioned in the last figure, in the average number of patents, the utility models account for most part of them. What is more, the utility model is also the most fast-growing one as it is granted

[4]notice scale of the y-axis of invention is one hundred fold less than the other two

quickly and easily. 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 (*27*). The requirements in each step make the number of invention much less than utility model and design patent.

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

Not only a longer period provided for the protection of invention, but also higher application fee. 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. As what is discussed in the empirical econometric model part, the numbers of patents are discrete and there may exist dispersion. The frequency of total patents as well as sub-patents are shown below.

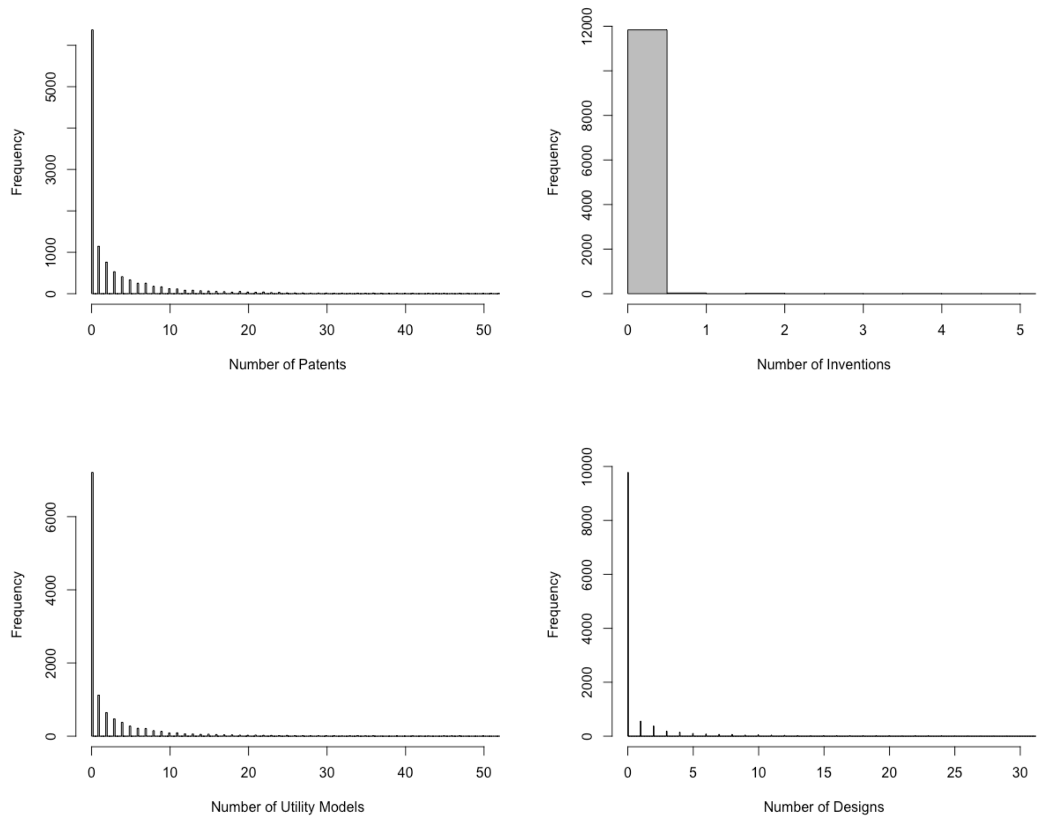

Figure 6: The annual average invention, utility model and design

A descriptive summary is also listed in the appendix and combine with the frequency figure, it could be seen that over half of the observations show zero number of patents or sub-patents. This undeniably means there is a strong dispersion of the patents distribution. Continuing to analyze the trend of patents growing, the total amount is sustained growing from 1995 in most of time. The utility models trend is similar with the total amount. That may be due to utility models accounting for most of patents. The inventions, which are tougher to get, fluctuate less frequently with a sudden increase in 2011. Design showed peak near 2000, 2010 and 2015.

The characters of firms involved in our analyses of how environmental policies influence patents are also shown blow.

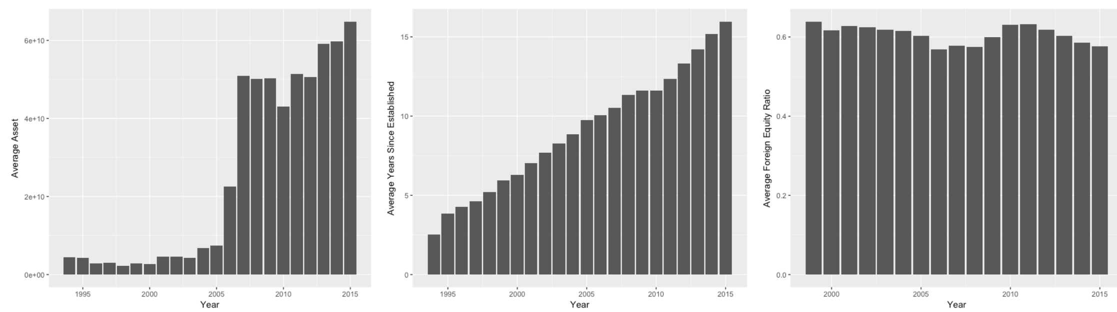

Figure 7: The average aggregate asset, the average foreign share equity and the average years since established

Empirical Results

The DIDID results are explicated from table 2 to 6. First, due to the data limitation, only AQCZ policy was tested for R&D expenditures. Both TCZ policy and AQCZ policy are tested about whether they influenced the number of patents of a firm.

I. The R&D Results

Table 2 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 mainly focus on all three interaction terms controlled one and the interaction coefficients are significantly positive. This means the AQCZ policy proded 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 figures below, firm data are separated into two groups: infuenced by the AQCZ policy and not. We calculated the average R&D expenditures of firms and could see that R&D expenditures in the group involved in the AQCZ policy increased much more than the other one after 2012.

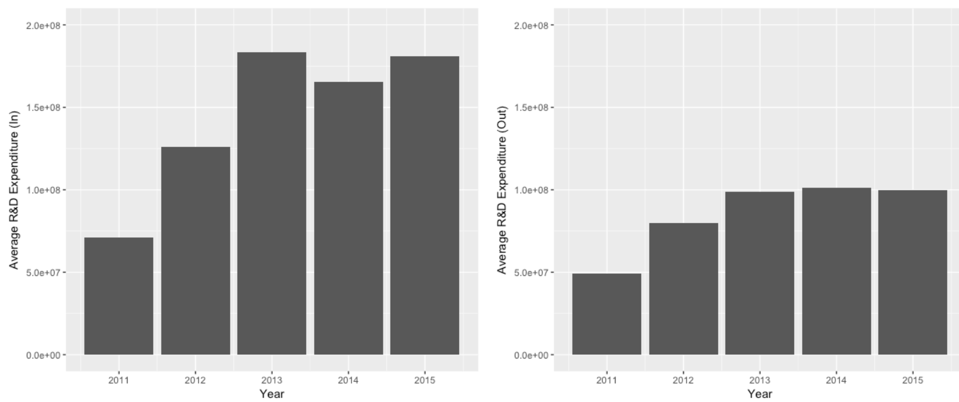

Figure 8: Firms in and out of AQCZ implemented area's average R&D expenditures

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 R&D activities. The result violates part of The Porter Hypothesis, because what we know 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 tested how 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. Again, we also only focus on the DIDID model with three effects controlled. The results are in favor of the Porter Hypothesis again. Interaction coefficients are significant positive no matter other possible factors are considered or not. In the data description part, we 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 found that in the number of patents, foreign equity in management actually does not have any influence. The sign of foreign equity coefficients indeed show no significance. This result violates the derivative conclusion of the Porter Hypothesis again. But actually several empirical research found the characteristics of a firms capital structure has no impact on its environmental or pollution disposal. Tang (2009) used Corporate Social Responsibility (CSR) to measure several social responsibility of Chinese domestic companies and global companies, including environmental responsivity, but only found that there is no significant difference in their emphasis on environmental conservation (*38*). The following figures shows how the average number of patents in each firm changes across time.

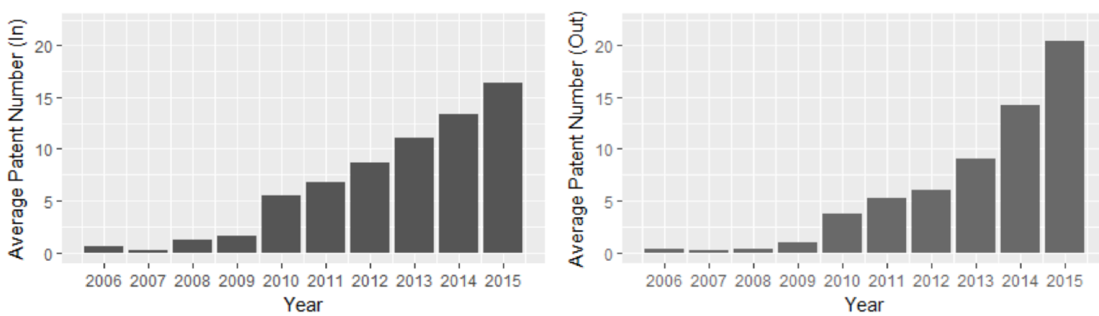

Figure 9: The average number of patents in each firm

It is also necessary to search the sub-items of patens if we want to learn more about the the Porter Hypothesis mechanism. As shown in the data description part, the requirements and the volumes of sub-items both vary a lot among these three items. Most of time, utility model accounts for highest percent of total patents, and in a certain period, design also dominated the total patents. Next, we make a regression of how 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, the 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 firms management. Utility model is often called Invention Lite as it shows similar purpose as invention but with much lower standards or requirements. Thus, when confront 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, 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

We could see the reason in the following figures, which shows how average number of patents changes from 1996 to 2005. It is obvious that no matter firms involved in the TCZ policy or not, the average number of patents both soared after 1998, the year when the TCZ was introduced. Nevertheless, we could see, in right figure, the one show how average number of patents changes in non-TCZ policy group, the percents increase of patents are much more than the left one.

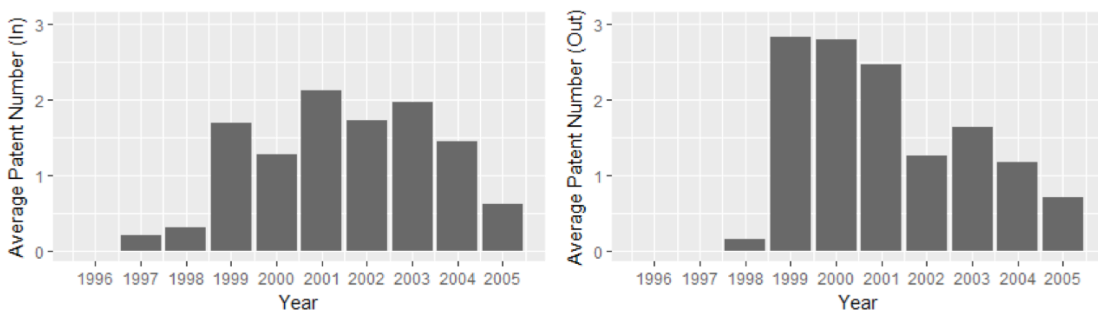

Figure 10: Average number of patents changes from 1996 to 2005

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 SO2 emissions with great target, is one thing, but if it was implemented strictly is another matter. So if the policy is 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 periods macroeconomic background. Then, again, 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	1.038e-17*** (3.323e-18)	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)	3.832e-18*** (9.057e-19)	—	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 number of invention before 2005 for most of firms got zero. From the regression results, we could also find it is suitable to skip 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 number. Hence, when design decreased due to the TCZ policy, the sign of total patents number also shows negative.

Robustness Check

I. Firms with Zero Patent

In our dataset, there are some firms without any patents. This means these firms is not relevant with innovation activity or they do not have the ability to invest in patenting. From the data description, there are over half samples in our dataset have zero patent. This might lead to biased estimation because in the regression, no matter they are in or out of the policies implemented zones, polluting or less polluting, and before or after the policies implemented, we cannot distinguish them through the number of patents. Thus, we drop the sample with zero patent and make regression again.

	Patents Number (Quasi-Poisson regression without 0 patent firm)					
AQCZ · Time · Pollution	0.5273*** (0.0619)	0.5638*** (0.1119)	0.5831*** (0.1202)	0.9149*** (0.2130)	0.2587* (0.1451)	0.4635* (0.2627)
Other Control Variables:						
Asset (log)	0.5786*** (0.0177)	—	0.6247*** (0.0164)	—	0.6218*** (0.0164)	—
Foreign Equity in Management	-0.3484* (0.1798)		-0.0991 (0.1558)		-0.1992 (0.1534)	
Years since established	0.1281 (0.0886)		—		—	
Province-Year Effects	NO		YES		YES	
Year-Industry Effects	NO		NO		YES	
Industry-Province Effects	NO		NO		YES	
Observations	4090	4090	4090	4090	4090	4090
Number of Firms	1209	1209	1209	1209	1209	1209

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

Table 7: DIDID Regression of Patent Number(0 number patent excluded) Concerning AQCZ

The result shows no big difference from the original model and the influence of AQCZ policy is significantly positive in 10% statistical level. The foreign equity in a firm still exerts no effect on the number of patents and asset plays a critical role in the patenting process. The benefit of dropping the zero number patent companies is that we can eliminate the bias of grossly low innovation ability samples, but this will also result in another bias source, because there are samples incentivized by the AQCZ policy and their patents number jumped from zero to positive. We do not need to worry about the biased estimation caused by the zero number patent firms.

II. 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. Concerining this, we need to distinguish to different levels firms influenced by a certain policy. Here, 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 gorvernment has more poewer to determine the annual targets for pollution control. Then we can construct our new model considering the policy stringency.

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

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

Here, we only 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 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 AQCZ stringency

In the regression results, the interaction terms of both patents and R&D expenditure are both still significant. Though we found the R-Square of R&D expenditure is larger than previous regression 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 occured 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.

III. 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) (*20*) The DIDID model with lags and leads terms are explicated below:

$$log(Pat)_{itk} = \sum_{t=-2}^{2} \beta_{2012+t} AQCZ_i \times Time_{2012+t} \times Pollution_k + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \tag{15}$$

$$log(R\&D)_{itk} = \sum_{t=-2}^{2} \beta_{2012+t} AQCZ_i \times Time_{2012+t} \times Pollution_k + \sigma_{it} + \omega_{tk} + \phi_{ki} + X'_{itk}\lambda + \varepsilon_{itk} \tag{16}$$

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} caputures two years lag to two years lead effects. We plot the results of coefficients.

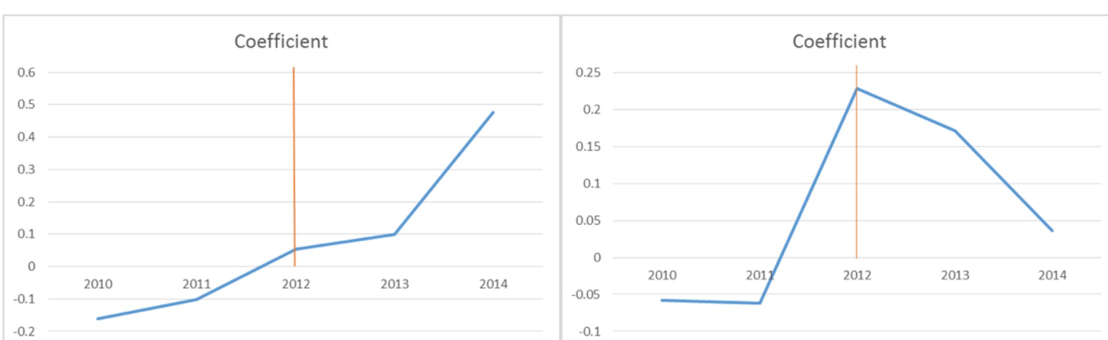

Figure 11: Time Changing Coefficients (Left: R&D Expenditures, Right: Patents Number)

From the figures above, no matter R&D expenditures or patents number, we can notice that there is 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.

IV. Placebo Test

In order to make our finding more solid, we decide to make a test to see if it is really the AQCZ policy that lead to the increase of 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 AQCZ policy. Then, we stochastically set 77.18% of the total firms as AQCZ policy influencing ones, or say dummy variable for AQCZ policy equals 1. And the rest are set as 0 valued dummy variable. This step eliminates the effects of AQCZ policy. We rule out incomplete samples in different regression models. The following table shows the regression results when the AQCZ policy variable are randomly set.

	AQCZ Policy Placebo Test			
	R&D Expenditure		**Number of Patents**	
$AQCZ_{Sto} \cdot Time \cdot Pollution$	0.0302 (0.0403)	0.0656 (0.0457)	0.2054 (1.9801)	0.3216 (1.9360)
Other Control Variables:				
Asset (log)	0.6570*** (0.0129)	—	10.4543*** (0.4683)	—
Foreign Equity in Management	0.4269*** (0.0913)		14.1629*** (3.4542)	
Province-Year Effects	YES		YES	
Year-Industry Effects	YES		YES	
Industry-Province Effects	YES		YES	
Observations	6987	8617	7944	7944
Number of Firms	1811	2289	1488	1488

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

The placebo test indicates there is no significant influence of interaction term when the AQCZ policy variable was randomly set. The coefficient is much smaller than our original model and very close to zero. Next, 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 no matter the coefficient of R&D expenditures or the number of patents obeys normal distribution with mean value of zero.

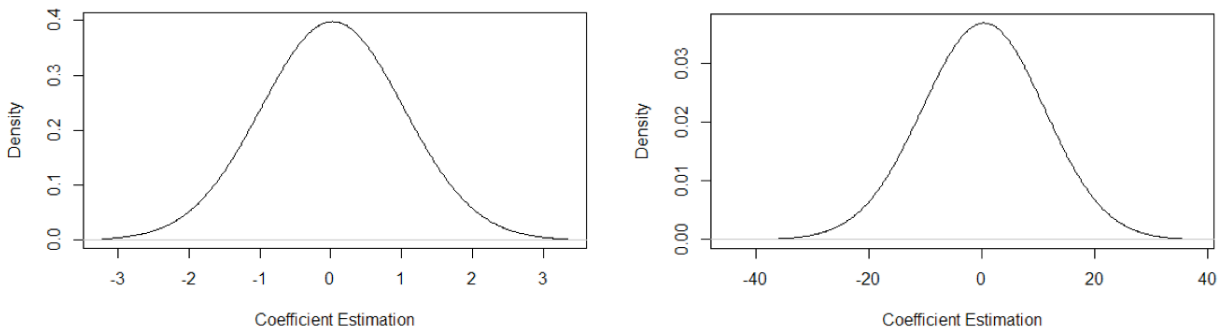

Figure 12: Distribution of Coefficient Estimation Density (Left: R&D Expenditures, Right: Patents Number)

By this placebo test, we confirm again that AQCZ policy did influence the firms innovation abilities. 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, in the context of the Porter Hypothesis. The Porter Hypothesis predicts that strict and well-designed environmental regulation will positively impact innovation ability by removing the incentive to impose negative externalities on the environment and forcing creativity within constraints. The impact of the two policies in our study is identified by the comparison of the outcome variable for 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 and biased estimation. By comparing innovation outcomes for firms in industries likely to be affected by policies, before and after implementation, with firms that were unlikely to be affected by the policies, before and after implementation, 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 number of patents as indicators of innovation ability. 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 that marked the beginning of a serious government effort at environmental regulation, actually had a negative effect on the number 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 but had no effect on high-quality patents, 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 firms 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.

Our interpretation of these mixed results hinges on a feature of the Chinese patent system that we learned about in our research, but were unable to fully account for in our model. In China, the highest level of patent is significantly more expensive and time-consuming to pursue. ”Innovation” patents are generally only pursued in close collaboration with the government by the top tier firms and universities that have the resources to fund the lengthy application process and the infrastructure incentives to capture the resulting value over time. Under these conditions, we cannot expect that all Chinese innovation is captured at the right level in our data. Since inventions patented under the ”utility” or ”design” specification still receive some form of legal protection and are easier to obtain, we hypothesize that these lower patent classes are being used as a minimally effective substitute in some cases and are indeed capturing a relevant measure of innovation. In this context we interpret the uptick in overall patents under the AQCZ policy as tentative support for the Porter Hypothesis, but more research, both qualitative and quantitative, is needed to fully unravel the underlying relationship in a Chinese context.

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. To our knowledge no other papers have looked at innovation outcomes in China because the data have not been available to researchers. Secondly, we introduce the concept of DIDID to Porter Hypothesis and innovation outcomes 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 the policies and biased estimation. Though we do not resolve these endogeneity concerns entirely, we believe our paper makes an important methodological contribution research in the area of environmental policy and innovation.

Appendix

Table 10: Two Control Zones Cities List

Province	**Cities**	**Province**	**Cities**	**Province**	**Cities**	**Province**	**Cities**	**Province**	**Cities**
Beijing	Beijing	**Shanghai**	Shanghai		Pingxiang		Changde	**Sichuan**	Chengdu
Tianjin	Tianjin	**Jiangsu**	Nanjing		Jiujiang		Zhangjiajie		Zigong
Hebei	Shijiazhuang		Wuxi		Yingtan		Yiyang		Panzhihua
	Tangshan		Xuzhou		Ganzhou		Chenzhou		Luzhou
	Handan		Changzhou		Jian		Huaihua		Deyang
	Xingtai		Suzhou	**Shandong**	Jinan		Loudi		Mianyang
	Baoding		Nantong		Qingdao	**Guangdong**	Guangzhou		Suining
	Zhangjiakou		Yangzhou		Zibo		Shaoguan		Neijiang
	Chengde		Zhenjiang		Zaozhuang		Shenzhen		Leshan
Shanxi	Taiyuan		Taizhou		Tantai		Zhuhai		Nanchong
	Datong	**Zhejiang**	Hangzhou		Weifang		Shantou		Yibin
	Yangquan		Ningbo		Jining		Foshan		Guangan
	Shuozhou		Wenzhou		Taian		Jiangmen		Meishan
	Yuncheng		Jiaxing		Laiwu		Zhanjiang	**Guizhou**	Guiyang
	Xinzhou		Huzhou		Dezhou		Zhaoqing		Zunyi
	Linfen		Shaoxing	**Henan**	Zhengzhou		Huizhou		Anshun
Inner Mongolia	Huhhot		Jinhua		Luoyang		Shanwei	**Yunnan**	Kunming
	Baotou		Quzhou		Anyang		Qingyuan		Qujing
	Wuhai		Taizhou		Jiaozuo		Dongguan		Yuxi
	Chifeng	**Anhui**	Wuhu		Sanmenxia		Zhongshan		Zhaotong
Liaoning	Shenyang		Maanshan	**Hubei**	Wuhan		Chaozhou	**Shaanxi**	Xian
	Dalian		Tongling		Huangshi		Jieyang		Tongchuan
	Anshan		Huangshan		Yichang		Yunfu		Weinan
	Fushun		Xunacheng		Ezhou	**Guangxi**	Nanning		Shaoluo
	Benxi		Chaozhou		Jingmeng		Liuzhou	**Gansu**	Lanzhou
	Jinzhou	**Fujian**	Fuzhou		Jingzhou		Guilin		Jinchang
	Fuxin		Xiamen		Xiaming		Wuzhou		Baiyin
	Liaoyang		Sanming	**Hunan**	Changsha		Guigang		Zhangye
	Huludao		Quanzhou		Zhuzhou		Yulin	**Ningxia**	Yinchuan
Jinlin	Jilin		Zhangzhou		Xiangtan		Hezhou		Shizuishan
	Siping		Longyan		Hengyang		Hechi	**Xinjiang**	Urumqi
	Tonghua	**Jiangxi**	Nanchang		Yueyang	**Chongqing**	Chongqing		

Table 11: Air Quality Control Zones Cities List

Region	**Province**	**Cities**	**Area**(10,000km^2)
Beijing-Tianjin-Hebei	Beijing, Tianjin, Hebei	Beijing, Tianjin, Shijiazhuang, Tangshan, Qinhuangdao, Handan, Xingtai, Baoding, Zhangjiakou, Chengde, Changzhou, Langfang, Hengshui; 13prefecture-levelcities in total	21.9
Yangtze River Delta	Shanghai, Jiangsu, Zhejiang	Shanghai, Nanjing, Wuxi, Xuzhou, Changzhou, Suzhou, Nantong, Lianyungang, Huaian, Yancheng, Yangzhou, Zhenjiang, Taizhou, Suqian, Hangzhou, Ningbo, Wenzhou, Huzhou, Jiaxing, Shaoxing, Jinhua, Quzhou, Zhoushan, Taizhou, Lishui; 25 prefecture-level cities in total	21.07
Pearl River Delta	Guangdong	Guangzhou, Shenzhen, Zhuhai, Foshan, Jiangmen, Zhaoqing, Huizhou, Dongguan, Zhongshan; 9 prefecture-level cities in total	5.47
Central Liaoning city cluster	Liaoning	Shenyang, Anshan, Fushun, Benxi, Yingkou, Liaoyang, Tieling; 7 prefecture-level cities in total	6.5
Shandong city cluster	Shandong	Jinan, Qingdao, Zibo, Zaozhuang, Dongying, Yantai, Weifang, Jining, Taian, Weihai, Rizhao, Linyi, Dezhou, Liaocheng, Binzhou, Heze; 17 prefecture-level cities in total	15.67
Wuhan region city cluster	Hubei	Wuhan, Huangshi, Ezhou, Xiaogan, Huanggang, Xianning, Xiantao, Qianjiang, Tianmen; 6 prefecture-level cities and 3 county-level cities in total	5.94
Changsha-Zhuzhou -Xiangtan city cluster	Hunan	Changsha, Zhuzhou, Xiangtan; 3 prefecture-level cities in total	2.8
Chengdu-Chongqing city cluster	Sichuan, Chongqing	Chongqing, Chengdu, Zigong, Luzhou, Deyang, Mianyang, Suining, Neijiang, Leshan, Nanchong, Meishan, Yibin, Guangan, Dazhou, Ziyang; 15 prefecture-level cities in total	22.14
Straits Fujian city cluster	Fujian	Fuzhou, Xiamen, Putian, Sanming, Quanzhou, Zhangzhou, Nanping, Longyan, Ningde, Pingtan compressive experimental region; 9 prefecture-level cities and 1 experimental region in total	12.4
Central and northern Shanxi city cluster	Shanxi	Taiyuan, Datong, Shuozhou, Xinzhou; 4 prefecture-level cities in total	5.69
Shaanxi Guanzhong	Shaanxi	Xian, Tongchuan, Baoji, Xianyang,	5.5

city cluster		Weinan, Yanglin national agricultural high-tech demonstration zone; 5 prefecture-level cities and one deputy provincial development zone in total	
Gansu-Ningxia city cluster	Gansu, Ningxia Hui Autonomous Region	Lanzhou, Baiyin, Yinchuan; 3 prefecture-level cities	4.33
Urumqi city cluster in Xinjiang	Xinjiang Uygur Autonomous Region	Urumqi, Changji, Fukang, Wujiaqu; 1 prefecture-level city and 3 county-level citiesin total	3.15

Table 12: China Sectoral Classification System

Primary sector	Agriculture	Farming Forestry Animal husbandry Fisheries Agricultural services
Secondary sector	Mining and quarrying	Coal mining and dressing Petroleum and natural extraction Ferrous metal mining and dressing Nonferrous metals mining and dressing Nonmetal minerals mining and dressing Other minerals mining and dressing
	Manufacturing	Food processing Food manufacturing Beverage manufacturing Tobacco processing Textile industry Garments and other fiber products Leather, furs, down and related products Timber processing, bamboo, cane, palm fiber and straw products Furniture manufacturing Papermaking and paper products Printing industry Cultural, educational and sports goods Petroleum processing and coking Raw chemical materials and chemical products Medical and pharmaceutical products Chemical fiber Rubber products

		Plastic products Nonmetal mineral products Smelting and pressing of ferrous metals Smelting and pressing of nonferrous metals Metal products Ordinary machinery Special purpose equipment Transport equipment Weapons and ammunition manufacturing Electric equipment and machinery Electronic and telecommunications equipment Instruments, meters, cultural and office equipment Other manufacturing
	Utilities	Production and supply of electric power, steam and hot water Production and supply of gas Production and supple of tap water
	Construction	Building projects Installation of lines, pipelines and equipment Renovation and decoration
	Geological prospecting and water management	Geological prospecting Water management
Third sector	Transport, storage, post and telecommunication services	Railway transport Road transport Pipeline transport Water transport Air transport Subsidiary transport business Other transport Storage Post and telecommunication
	Wholesale and retail trades and catering services	Wholesale of foods, beverages, tobacco and consumer goods Wholesale of energy, raw materials, machinery and electronic equipment Other wholesale Retail trade Commission trade Catering services

	Finance and insurance	Finance Insurance
	Real estate	Real estate development Real estate administration Real estate agencies
	Social services	Public services Resident services Hotels Leasing Tourism Entertainment News and consulting Computer applications Other social services
	Health care, sports and social welfare	Health care Sports Social welfare and insurance
	Education, culture and arts, radio, film and television	Education Culture and arts Radio, film and television
	Scientific research and s polytechnic service	Scientific research Polytechnic services
	Government agencies, party agencies and social organization	Government agencies Party agencies Social organization Autonomous grassroots organizations
	Others	Other

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