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ENVIRONMENTAL REGULATIONS AND COMPETITIVENESS: EVIDENCE BASED ON CHINESE FIRM DATA

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Environmental Regulations and Competitiveness: Evidence based on Chinese firm data

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Abstract

This paper provides empirical evidence in support of the Porter hypothesis that tighter environmental regulations can increase productivity under certain circumstances. It builds on a theoretical model in which environmental regulations induce firms to adopt more efficient technologies. Using Chinese firm-level data covering a ten-year period, the empirical study examines the effects of two specific policy instruments - the pollution levy and regulatory standards - on firm productivity. It finds a bell-shaped relationship between pollution levies and the total factor productivity of firms, indicating that an increase in the pollution levy rate can be associated with higher productivity. In addition, the study investigates the effect of pollution emission standards on firm productivity and identifies an initial negative effect which diminishes after a period of two to three years.

Keywords: Environmental regulations, Innovation, Productivity, Porter hypothesis, China

JEL Classifications: D2, F18, Q52, Q55, Q56

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1 Introduction

The effects of environmental regulations on the competitive performance of industries have been the subject of heated debate since the start of the environmental movement in the early 1970s. Two opposing arguments are at the heart of this debate. On the one hand, opponents of stricter environmental regulations argue companies tend to locate their business activities in countries or regions where environmental regulations are relatively lax, resulting in so-called “pollution havens”. On the other hand, Porter and Van der Linde (1995) argue that the costs of compliance with environmental regulations will be offset by cost reductions resulting from technological innovation stimulated by these regulations. This argument is also known as the “Porter hypothesis”. According to Porter, an increase in environmental standards can actually improve competitiveness, offset compliance costs and encourage firms to upgrade to new and cleaner technologies.

Empirical analysis on the economic cost of environmental regulations can be traced back to the 1970s, and most studies were conducted in the United States. Jaffe et al. (1995) provides a review of the literature. Notably, Levinson (1996) examines the effect of state environmental regulations of varying stringency on the location choice of firms, and shows that interstate differences in environmental regulations do not systematically affect the location choices of most manufacturing plants. Becker (2011) measures the effects of environmental regulations on plant-level productivity in all U.S. manufacturing industries employing spatial-temporal variations in environmental compliance costs. The results suggest that, for the average plant, there is no statistically significant effect on productivity. Greenstone et al. (2012) used detailed production data from 1.2 million U.S. plant observations drawn from the 1972-1993 *Annual Survey of Manufacturers*, and conclude that among surviving polluting plants, stricter air quality regulations are associated with a roughly 2.6 percent decline in total factor productivity (TFP).

Since Porter and Van der Linde (1995) introduced the concept that properly designed environmental standards can trigger innovation and induce technological change, a growing literature has looked at the positive effects of innovation. See Ambec et al. (2013) for an overview of the theory and empirical evidence on the Porter hypothesis. Most empirical research focuses on the relationship between regulations and innovation, and the evidence remains inconclusive. For example, Jaffe and Palmer (1997) find that lagged environmental compliance expenditures have a significant positive effect on R&D expenditures. Berman and Bui (2001) show increases in productivity among oil refineries in the United States, despite heavy compliance costs in response to local air pollution regulations. Studies focusing on environmentally related patents find a positive relationship between the number of successful green patents with environmental regulations (Johnstone et al., 2010;

Popp, 2006; Lanoie et al., 2011).

This study employs a rich Chinese firm-level dataset to evaluate the effects of Chinese environmental regulations on productivity of firms. As a rapidly-growing developing country, China provides a unique context to study the effects of environmental regulations. In the last three decades, China's remarkable economic growth dwarfed many other economies, but it has also brought serious environmental degradation. In recent years, recognizing the danger of environmental degradation and the increasing popular demand for better environmental quality, the Chinese government has implemented various pollution control policies.

A few studies in the literature investigate the impacts of environmental regulations and industrial pollution controls in China. For example, Jiang et al. (2014) examine firm-level emission data and find that both foreign-owned firms and domestic publicly-listed firms show less intensive pollutant emissions compared to state-owned enterprises (SOEs). The study also finds that larger firms, firms in industries that export more, and firms with more educated employees pollute less; and that better property rights protection is negatively correlated with pollutant discharges over and beyond the national standards. Jefferson et al. (2013) exploit the plausibly exogenous variation in regulatory stringency generated by the Two Control Zone policy in China to find evidence that environmental regulations induce pollution-intensive firms to improve economic performance, whereas energy-intensive firms suffer from negative externalities of the regulations.

The current paper is one of the first studies to systematically look at the effect of different pollution control regulations on firm productivity. Environmental regulations may affect productivity at the firm-level in at least two ways. First, compliance with environmental regulations may require firms to divert inputs - capital, labor, material inputs, etc. - towards the production of environmental quality, resulting in lower productivity. Second, regulations may necessitate changes in the production process and induce firms to adopt more efficient, cleaner technologies. This study presents evidence in favour of a more recent approach which views environmental policy as a positive force leading to increased productivity and enhanced competitiveness.

The analysis builds on a theoretical model where tighter environmental regulations induce firms to upgrade production technologies, resulting in both pollution reduction and productivity increase under certain conditions. The empirical analysis examines two particular policy instruments - the pollution levy (or pollutant tax) and pollution emission standards - and their effects on the total factor productivity (TFP) of firms. It finds evidence in support of the Porter hypothesis. With regards to the pollution levy, it discovers a non-linear correlation between the effective water levy and firm productivity, suggest-

ing that a pollution levy does not necessarily harm productivity; on the contrary, higher pollution levy could induce firms to upgrade to cleaner technologies and at the same time increase productivity. In particular, the study identifies a threshold of the pollution levy where a higher levy rate corresponds to higher productivity. The paper also investigates the effects of industry-specific pollution emission standards on productivity and finds that, although the introduction of a pollution emission standard can lead to an initial drop in productivity, the negative effect diminishes over a period of three years.

The findings in this paper are different from similar studies conducted in industrialized countries, where a negative correlation is often observed between environmental regulations and productivity. The discovery of a non-linear relationship between pollution control measures and productivity in China is of important policy relevance. Compared with industrialized countries which find themselves at the efficient production frontier, firms in a developing country like China tend to rely on low production technologies, and are therefore more likely to switch to cleaner and more efficient technologies in response to stringent environmental regulations, resulting in both productivity increases and emission reductions. The findings in the study can also be potentially relevant in other developing countries going through a rapid economic transition.

The remainder of the paper proceeds as follows. Section 2 gives a brief introduction of China's environmental regulations. Section 3 presents a simple model where environmental regulations in the form of a pollution levy and emission standards lead to higher productivity. Section 4 introduces the data. Section 5 specifies the empirical strategy and reports the results. Section 6 concludes.

2 Institutional background¹

China's legal and institutional development of environmental protection goes back to the 1970s. The *Environmental Protection Law* (EPL), which was first enacted in 1979 on a provisional basis and which formally came into effect in 1989, is the main legal basis for environmental management in China. The EPL lays out general principles for environmental protection and describes key instruments for environmental management. It requires enterprises to assess the environmental impacts of proposed projects and comply with all relevant environmental standards. This statute also clarifies which environmental regulations should be managed and enforced at national level, and which ones at local

¹Summary based on OECD (2006), *Environmental Compliance and Enforcement in China: An Assessment of Current Practices and Ways Forward* (Draft study presented at the second meeting of the Asian Environmental Compliance and Enforcement Network, 4-5 December 2006, in Hanoi, Vietnam). <http://www.oecd.org/environment/outreach/37867511.pdf>

level. In addition, the EPL recognizes the rights of organizations and individuals to report cases of pollution and file charges against polluters.

In 1988, the State Environmental Protection Agency (SEPA) was formed alongside numerous local Environmental Protection Bureaus (EPBs) throughout the nation. In 2008, SEPA was replaced by the Ministry of Environmental Protection (MEP). Over the past 30 years, many environmental protection organizations other than the EPBs have also been formed at both the national and local (provincial, city, or county) levels. According to the data released by MEP, China had established 12,215 environmental protection institutions by the end of 2008, with 393 at the national and provincial levels.²

Due to the different levels of economic development across different regions in China, local governments and authorities are encouraged to institute local rules and regulations that are adapted to local circumstances - as long as they do not conflict with those at the national level. By 2009, China had established or passed one environmental protection law, 26 individual environmental laws, over 50 administrative regulations concerning environmental protection and over 1600 local environmental decrees and rules.

There are a number of regulatory and economic instruments dealing with industrial pollution control in China. The most important ones include (1) the Pollution Levy System, (2) Emission/discharge and environmental quality standards, (3) the Discharge Permit System, and (4) Shutting down, merging and transferring of existing polluting plants. In addition, newly-constructed industrial plants have to conduct an Environmental Impact Assessment and integrate pollution treatment into the design, construction and operation of a new plant (the so-called “Three Simultaneities” requirement). Below I briefly describe the two most commonly used policy instruments - the Pollution Levy System and Emission/Discharge Standards.

2.1 Pollution Levy System

China’s pollution levy system was first introduced as a legal provision in the *Water Pollution Prevention and Control Law* of 1984. Subsequently, regulations such as the *Interim Measures for Pollution Levy* were established to stipulate the implementation of the system. In 2003, the *Administrative Regulations on Pollution Discharge Levy* were enacted by the State Council, which marked a major shift in the system.

Originally, pollution that exceeded emission/discharge standards were subject to a fine. Since the introduction of the new pollution regulation in 2003, the calculation of the pollution levy is no longer based on the amount of pollution exceeding the standards, but

²China Environment Yearbook, 2009 (in Chinese)

on the total amount of emissions generated by the firm. The formula used for calculating the levy incorporates both the volume of total wastewater/air discharge and the degree to which each pollutant concentration exceeds the standard. The polluter is required to pay levies on the sum of the highest three pollutant-specific levies rather than for a cumulative amount of all pollutant emissions. A detailed description of the pollution levy system in China can be found in Appendix B.

Although the formulas to calculate the pollution levy is determined by the national pollution levy regulation, in practice, the levy rate varies substantially across different provinces. There are four major sources of variations in provincial pollution levy rates. First, concentration standards of hazardous pollutants are set jointly by the national and local governments and can vary by region. Second, the pollution levy standards differ by pollutant. According to China's pollution levy regulations, the actual levy is the greatest of all potential levies for each pollutant discharged by a plant before 2003, and the sum of the three highest potential levies calculated for each pollutant after 2003, differences in the composition of pollutants in pollution emissions could lead to different levy rates. Third, there are significant differences in enforcement capacity at the local level. Studies indicate that more frequent inspections by local EPBs can lead to higher reported pollution and thus higher pollution levies (Lin, 2013). Finally, the levy can be reduced or even eliminated at the discretion of local regulators after inspections. Such leeway introduces considerable variation into regional enforcement practices of the pollution levy system.

Until recently, the revenue collected from the pollution levy was used to cover the operating expenses of environmental authorities. Currently, the revenue is directed towards environmental protection measures and the purchasing of monitoring equipment. Of the total pollution levy revenues, 10% is transferred to the central government and 90% remains at the sub-national level.

2.2 Environmental Standards

The 1989 Environmental Protection Law authorized SEPA to establish two types of national standards: environmental quality (ambient) standards and pollution emission standards. Ambient standards designate the maximum allowable concentrations of pollutants in the atmosphere. Emission standards, on the other hand, designate the maximum allowable concentrations of pollutants in industrial pollution emissions. Local governments may create ambient and emission standards for pollutants not specified in the national standards, and they may also establish stricter upper limits for pollutants compared to those set by the national standards. The pollution emission/discharge standards provide

a basis for the EPB inspection activities.

China issued the first ambient environmental quality standard for surface water in 1983. The standard was subsequently updated in 1988, 1999 and 2002. In addition, the first *Integrated Wastewater Discharge Standard* was issued in 1988 and updated in 1998. The wastewater discharge standard establishes the upper limits for 69 pollutant concentrations and the allowable water discharges for some industries. In addition, a range of water discharge and emission standards target specific industries including chemicals, coal mining and processing, electroplating, iron and steel, municipal wastewater treatment, pharmaceuticals, pesticides, pulp and paper, etc.

Ambient air quality has been regulated in China since 1982, when initial limits were set for TSP (Total Suspended Particulates), SO₂, NO₂, lead, and BaP (Benzo(a)pyrene). In 1996, the standard was both strengthened and expanded under the new *National Ambient Air Quality Standard*. In February 2012, China released a new ambient air quality standard, GB 3095-2012, which sets limits for the first time on PM_{2.5}. The new standards will take full effect nationwide in 2016, but many cities and regions in China are required to implement the standards earlier than the national timeline. China also issued a range of air pollution emission standards targeting specific industries and sectors, such as cement, ceramics, coal, minerals, thermal power industries, etc., at the national and provincial level.

Appendix C lists the national and provincial pollution emission standards published since 1996.

3 Theoretical Background

The theoretical framework of the analysis is based on the New Economic Geography model. The model features increasing returns to scale, monopolistic competition, and trade costs based on τ , τ and τ . It takes into account the complexity of investment determinants such as: production factor endowments (labor, capital, etc.), local market size, and access to other important markets.

3.1 New Economic Geography Model

In the model, I assume the manufacturing sector produces a continuum of differentiated goods under increasing returns to scale in an environment of monopolistic competition (η). The economy consists of $r = 1, \dots, R$ regions. Consumers have constant elasticity

of substitution (CES) sub-utility functions for each industry. I assume that each firm produces one variety. Maximizing the sub-utility function subject to budget constraint yields the demand curve for the representative variety in the representative industry as

$$q_{rj} = \frac{(p_r \tau_{rj})^{-\sigma}}{\sum_{r=1}^R n_r (p_r \tau_{rj})^{1-\sigma}} Y_j \quad (1)$$

where p_r is the price of the variety produced in region r . $\sigma > 1$ is the constant elasticity of substitution, τ_{rj} is the trade cost including all transaction costs related to the shipment of goods from region r to market j . n_r is the number of varieties produced in region r and Y_j denotes the expenditure in a representative industry in market j .

One of the most important factors for the firm's location decision are its production costs. The total production cost in every potential location takes the following form: $c_r q_r + F_r$, where q_r is the total production of the representative firm in the region r , i.e. $q_r = \sum_j q_{rj}$, and c_r is its marginal cost of production. The increasing returns to scale result from fixed costs F_r related to the initial cost of launching an investment activity/creating an enterprise in region r .

In the model of ? and ?, the price is a simple mark-up on the marginal cost: $p_r = c_r \frac{\sigma}{\sigma-1}$. By substituting it in equation (1), I obtain the following expression for the quantity that a representative firm produces in region r to ship to market j :

$$q_{rj} = \frac{\sigma - 1}{\sigma} \frac{(c_r \tau_{rj})^{-\sigma}}{\sum_{r=1}^R n_r (c_r \tau_{rj})^{1-\sigma}} Y_j \quad (2)$$

A firm will aim to maximize its gross profit in every market. The gross profit earned in each market j for a firm producing in region r is:

$$\pi_{rj} = (p_r - c_r) \tau_{rj} q_{rj} = \frac{(c_r \tau_{rj})^{1-\sigma}}{\sigma G_j} Y_j \quad (3)$$

where I denote $G_j = \sum_r n_r (c_r \tau_{rj})^{1-\sigma}$, it represents the competition from firms located in other regions. Profit decreases in local production costs c_r and the trade costs to reach market j , and increases with the expenditure of market j . The denominator contains the corresponding characteristics of competing suppliers and a factor σ capturing the idea that when varieties are less differentiated from each other, competition is fiercer and therefore profits are lower.

Summing the gross profits realized in each market and subtracting the fixed cost F_r to

establish a plant in region r , I obtain the aggregated net profit that a representative firm could earn in each potential location r .

$$\Pi_r = \frac{c_r^{1-\sigma}}{\sigma} \sum_j \tau_{rj}^{1-\sigma} \frac{Y_j}{G_j} - F_r = \frac{c_r^{1-\sigma}}{\sigma} MP_r - F_r \quad (4)$$

where $MP_r = \sum_r \tau_{rj}^{1-\sigma} \frac{Y_j}{G_j}$ represents the Market Potential for a firm located in region r . The market potential includes access to markets within and outside of the region. It is negatively correlated with ‘iceberg’ trade costs, while positively correlated with the share of income Y . The profit equation in region r suggests that firms face a tradeoff between low production costs and high market potential.

When a firm chooses its location, it considers the potential profits in each region. I assume that fixed costs do not differ across locations, i.e. $F_r = F \forall r$. As monotonic transformations do not affect the ordering of potential locations, I add fixed cost F to equation (4), multiply the results by σ , and take natural logarithms. I denote the result as U_r , which represents the profitability of a representative firm located in region r .

$$U_r = \ln(\Pi_r + F) + \ln \sigma = \ln MP_r - (\sigma - 1) \ln c_r \quad (5)$$

To take into account the variable production costs in region r , I assume a Cobb-Douglas cost function. There are three production factors, namely capital, labor and pollution. The marginal cost function is thus expressed as: $c_r = \frac{1}{A_r} w_r^\alpha k_r^\beta l_r^\theta$, where w_r , k_r and l_r are cost of labor, capital, and pollution in region r , and $\theta = 1 - (\alpha + \beta)$. The cost share of labor in the firm’s production process is noted by α , of capital by β , and of pollution by θ . A_r represents the average total factor productivity in region r . With this specification, equation (5) can be rewritten as follows:

$$U_r = \ln MP_r + (\sigma - 1) \ln A_r - \alpha(\sigma - 1) \ln w_r - \beta(\sigma - 1) \ln k_r - \theta(\sigma - 1) \ln l_r \quad (6)$$

Equation (6) predicts that the profitability of a firm settled in a region r is an increasing function with regards to the market potential and the average factor productivity in a region, and that it decreases with regards to variable production costs. This specification represents the theoretical background for the empirical work that follows.

4 Data

The data used in this study comprises an unbalanced panel covering 768 four-digit industrial sectors and 437 locations over a period of 12 years. The following section gives a description of the variables used in the empirical analysis. The summary statistics are presented in Appendix 2.A.

4.1 Dependent variables

The dependent variables are defined as the annual output and the number of firms located in a region per industry and per year. In a discrete choice model of firms, I use firm-level data in the most polluting industries as the dependent variable. The information is calculated using the *Annual Survey of Industrial Firms* conducted by the Chinese National Bureau of Statistics. The survey contains information related to the business and operations of all Chinese stated-owned industrial firms and all private firms whose revenues are larger than 5 million RMB. The sample represents more than 90% of total sales in China, providing a unique window onto the economic changes that have reshaped the Chinese manufacturing sector in recent years.

China's industries are classified into 39 divisions, covering the mining (6 divisions), manufacturing (30 divisions) and utility (3 divisions) sectors. The mining sectors are excluded in the analysis because the locations of mining firms are largely driven by the distribution of natural resources, not by economic choices. That leaves 33 two-digit industry sectors in the dataset. I aggregate the firm-level data by city and by 4-digit industrial code. I also match the cities with the geographical information to obtain the cities' longitude and latitude coordinates.

4.2 Market potential

As shown in the theoretical model, the profitability of a firm located in a region depends on the market potential and the firm's production costs. The market potential of a region is positively correlated with population and average income, and negatively correlated with trade costs for accessing the markets in other regions.

I construct the "market potential" index according to the method introduced in ?, whereby the market potential of region r is $MP_r = \sum_j GDP_j / Dist_{rj}$. Trade costs between regions are proxied by the *distance* from region r to the capital of all provinces. The market

potential index is then calculated by summing the GDP of all provinces divided by the distances.

As there are no explicit inter-province trade barriers, the trade cost is mainly composed of transportation costs, measured by distance. The market potential index varies by city as the distances of each city to the provincial capitals vary by geographic coordinates. ? has shown that the ? market potential index outperforms more sophisticated, theory-derived measure of market potential in determining firms' location choices. In addition, I also include as a separate variable the GDP of the province where the industry is located to capture the agglomeration effect of production activities,

4.3 Industry pollution intensity

The pollution intensity of an industry is defined as the sum total of industrial pollution emissions divided by the total output of the industry, i.e. $\sum_p (E_{ip}/F_p)/Output_i$, where E_{ip} is the emission of pollutant p in industry i , F_p is the pollutant-specific conversion parameter, and the sum of pollution per industry i is normalized by the output of the industry.

The *China Environment Yearbook* reports pollution emissions by industry according to the 2-digit divisions of Chinese industrial classification. For each industry, the official statistics report the amounts of emissions of major pollutants, such as Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammonia Nitrogen for wastewater, Sulfur Dioxide (SO₂), Nitrogen Oxide (NO_x), industrial soot and dust for air pollutants. To make meaningful comparisons across pollutants, I convert all pollutants into COD and SO₂ equivalents using the conversion parameters published in official Chinese regulations and presented in Table 12 of Appendix 2.B.

The average industry pollution intensity ranges from 27.6 kilograms of pollution emission per 1000 RMB output in electricity and heating supply to 0.120 in communications equipment, computer and other electronic equipment manufacturing.

The industrial pollution data are collected by summing the self-reported numbers from selected firm samples to cities, provinces and adding them to the national level. Some researchers argue that such data are less reliable because firms and local governments have the incentive to under-report their emissions but to over-report their economic output and their pollution mitigating efforts (?). In addition, output-normalized pollution emission data tend to overestimate pollution intensity of industries producing low-value products.

To mitigate the measurement error, I convert the industry pollution intensities into dis-

crete indicator variables. A binary variable *High Pol* equals 1 for the most polluting industries (average pollution intensity above 4 ton/1000 RMB output). The variable *Medium Pol* equals 1 for the medium-polluting industries (average pollution intensity between 2 and 4 ton/1000 RMB output). Appendix 2.C reports the pollution intensity of all two-digit industries, and the division of high, medium and low-polluting industries.

4.4 Production costs

Following the New Economic Geography model, the total production cost faced by a firm is composed of labor, capital and environmental costs. The total factor productivity also affects the production efficiency. I describe in below the variables representing the production costs. Unless otherwise noted, the data are obtained from province-level statistics published by China’s National Bureau of Statistics.

Cost of pollution

The measurement of the pollution cost is a key variable in the study. China’s special pollution levy system provides the use of *de facto* levy rate as a proxy for environmental stringency. The *de facto* or effective levy rate is calculated as the total pollution levy divided by total pollutant emissions, i.e. effective levy $l_{rt} = L_{rt} / \sum_p E_{prt}$, where L_{rt} is the pollution levy collected in province r during year t and E_{prt} is the pollution emission of pollutant p in province r during year t , as reported in the China Environment Yearbook. To make meaningful comparisons across pollutants, the amounts of emissions by pollutant are converted into COD and SO₂ equivalents, which then enters the denominator of the effective levy formula.

Cost of labor

The cost of labor in each province is proxied as the average wage in each province, calculated as the industrial wage bill divided by the number of industrial workers.

While one might expect industrial activities to be deterred by high average wages, differences in worker skills could also determine the wage differences across regions. To capture the difference of skill levels, I use the ratio of educated population in each province to control for the skill level of labor. I define the variable *ratio skilled labor* as the percentage of the population with senior secondary education or beyond, and *ratio unskilled labor* as the percentage of the population who are either illiterate or have primary-level education at most.

Cost of capital

Capital costs are incurred for the purchase of land, buildings, construction and equipment to be used in the production of goods. Firms may be attracted to locations with lower cost of land, energy and other capital inputs. I capture this effect by including a price index of investment in fixed assets. The index includes the prices of main construction materials such as steel, timber, cement, local construction materials (such as brick, tile, calcareous ashes, sand, stone, etc.), chemical materials (such as oil paint, etc.), rent, machinery and equipment, the purchasing price of equipment, tools and instruments and the prices of other investments.

Infrastructure

The transportation and telecommunications infrastructure are likely to affect the operating cost of firms in a region, and could also affect the shipping costs not entirely captured by distance in the market potential index. I include additional variables to account for the varying density of transportation and telecommunication facilities in a region. Transportation infrastructure is measured by the length of highways and railways in kilometers, adjusted for provincial size. Telecommunications infrastructure is proxied by the number of telephone subscribers per 1000 inhabitants.

Total Factor Productivity

Total Factor Productivity (TFP) captures the technology and management efficiency of firms, and thus determines the cost of production. Although the TFP varies at firm level, industries located in one region are likely to share similar technologies and thus have a similar level of productivity. To derive the industry and city-level average TFP, I calculate the TFP at the firm level using the Olley and Pakes (1996) method and then aggregate the average TFP by city and by 4-digit industry division.

4.5 Special Economic Zones

In addition, since the 1980s, China has had Special Economic Zones (SEZs) which were set up as a way of attracting investment. The fiscal and operational incentives provided by the SEZs include tax reductions and exemptions, ease of company establishment, autonomy of operations, preferential access to materials and supplies, and streamlined bureaucracy. These preferential investment policy also lowers the operating costs of firms. I construct

an SEZ variable by adding 1 to a binary indicator if a city contains an SEZ or Coastal Development Area.

5 Empirical estimation

The empirical specification captures the effect of environmental measures on the production and location of industrial firms. It is based on the following equation:

$$y_{irt} = \beta_0 + \beta_1 l_{rt} + \beta_2 Pol_i * l_{rt} + \gamma X_{rt} + \delta_r + \eta_i + \varepsilon_{irt} \quad (7)$$

where the subscripts i , r and t indicate the industry, region and year respectively. The dependent variable y_{irt} is a measure of production activities, it can be the total output or the number of firms in industry i in city r and in year t . Pol_i are discrete variables indicating if the industry is high polluting or medium polluting. l_{rt} is the effective pollution levy that varies by province and time. X_{rt} represents a set of province-specific characteristics derived from the New Economic Geography model. In addition, I include δ_r and η_i as the city and industry fixed effects to control for possible omitted variable bias.

Similar as the empirical specification in ?, the parameter β_1 captures the “volume effect”: a positive (or negative) β_1 implies that higher environmental stringency in a region tends to encourage (or discourage) total output and the number of firms. The parameter β_2 captures the “composition effect”: a negative (or positive) coefficient means that more (or less) pollution-intensive industries are located in regions with weak environmental stringency.

5.1 Preliminary results

Table 1 summarizes the results of the preliminary estimation. Columns (1) and (4) present the baseline OLS regression without the fixed effects. The dependent variables are the logarithm of output or the number of firms, respectively; columns (2) and (5) report the results with city fixed effects; and columns (3) and (6) present the results including both industry and city fixed effects. The standard errors are clustered at the four-digit industry level and reported in parentheses.

As discussed earlier, the coefficient of the effective pollution levy (labeled $lnlevy$) captures a *volume effect* - the impact of the effective pollution levy on the overall amount of output and number of firms in all industries. In general, the pollution levy does not have

Table 1: Economic Geography Model Estimations

	Dependent Variable: <i>lnOutput</i>			Dependent Variable: <i>ln Number of firms</i>		
	(1)	(2)	(3)	(4)	(5)	(6)
<i>lnLevy</i>	0.0873* (0.0366)	0.1288** (0.0392)	0.1523*** (0.0309)	0.0841*** (0.0184)	0.0972*** (0.0207)	0.1692*** (0.0203)
High Pol × <i>lnLevy</i>	-0.2969* (0.1153)	-0.3303** (0.1200)	-0.3337*** (0.0886)	-0.1565** (0.0556)	-0.1846** (0.0613)	-0.2613*** (0.0627)
Medium Pol × <i>lnLevy</i>	-0.1276* (0.0649)	-0.1542* (0.0668)	-0.2479*** (0.0558)	-0.0568 (0.0331)	-0.0673 (0.0380)	-0.2512*** (0.0373)
<i>lnMarket</i> Potential	0.1265*** (0.0085)	-0.2043 (0.1258)	-0.1722 (0.1212)	0.0625*** (0.0040)	-0.3544*** (0.0651)	-0.3262*** (0.0653)
<i>lnGDP</i>	0.4922*** (0.0236)	0.1312 (0.1054)	0.1645 (0.0983)	0.0317*** (0.0020)	0.1629** (0.0537)	0.1707** (0.0529)
<i>lnwage</i>	0.3106*** (0.0529)	0.4196*** (0.0753)	0.4280*** (0.0738)	-0.1528*** (0.0257)	-0.3513*** (0.0409)	-0.3654*** (0.0396)
ratio skilled	0.0027*** (0.0003)	0.0013*** (0.0003)	0.0012*** (0.0003)	0.0017*** (0.0001)	0.0014*** (0.0002)	0.0015*** (0.0002)
ratio unskilled	0.0017*** (0.0002)	-0.0010** (0.0003)	-0.0008* (0.0003)	0.0018*** (0.0001)	0.0003* (0.0002)	0.0004* (0.0002)
<i>lnfixed asset</i> price index	-0.1473*** (0.0347)	3.6447*** (0.4436)	3.4886*** (0.4127)	-0.2227*** (0.0227)	2.2382*** (0.1820)	2.2135*** (0.1765)
highway density	-0.0108** (0.0038)	-0.0390*** (0.0051)	-0.0358*** (0.0047)	0.0214*** (0.0023)	-0.0051* (0.0026)	-0.0044 (0.0026)
railway density	0.5097*** (0.1094)	-0.5636 (0.4443)	-0.4537 (0.4395)	0.4388*** (0.0566)	0.7949** (0.2552)	0.7382** (0.2507)
telephone density	0.0074*** (0.0015)	0.0078*** (0.0019)	0.0067*** (0.0018)	0.0157*** (0.0010)	0.0190*** (0.0014)	0.0184*** (0.0013)
<i>lnTFP</i>	0.3437*** (0.0224)	0.3338*** (0.0237)	0.3043*** (0.0160)			
SEZ	0.4794*** (0.0251)	0.1118** (0.0428)	0.1090** (0.0418)	0.2236*** (0.0148)	0.1021*** (0.0240)	0.0989*** (0.0235)
constant	-0.7086** (0.2517)	-16.3130*** (1.8989)	-7.5969*** (1.5598)	0.9281*** (0.1259)	-10.5119*** (0.7975)	-1.2197 (0.7942)
City FE		Yes	Yes		Yes	Yes
Industry FE			Yes			Yes
Number of obs.	308844	308844	308844	444930	355995	355995
R ²	0.1772	0.2336	0.2891	0.1228	0.1880	0.2415
F	171.6816	133.6057	191.7685	114.2833	49.9784	58.9696

Standard errors are clustered at the four-digit industry level, reported in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

any deterrent effect on production activities: a positive coefficient of the $\ln\text{levy}$ variable suggest that a high level of environmental stringency can be positively correlated with total output and the number of firms.

The coefficient of the interaction of the pollution intensity indicator and the effective levy captures a *composition effect*, i.e. whether a high pollution levy discourages output and the number of firms in more polluting industries by a greater amount. As shown in Table 1, the interactions of the high pollution indicator and the $\ln\text{Levy}$ variable have negative and significant coefficients for the output and the number of firms, suggesting that production activities of polluting industries are more deterred by high pollution levies at the province level, compared to average industries.

To interpret the overall effect of the pollution levy on the output of polluting industries, the coefficients of the $\ln\text{Levy}$ variable and the pollution-levy interactions need to be read jointly.³ The results show that a 10% increase in the effective pollution levy is correlated with an approximate 2% decrease in total output of the most polluting industries. The effect of the pollution levy is relatively smaller in the medium polluting industries, where a 10% increase in the effective pollution levy is correlated with an approximate 0.5% decrease in total output in the medium polluting industries, according to baseline model.

The total number of firms in polluting industries is also negatively correlated with the effective pollution levy. According to the baseline OLS model, a 10% increase in the effective pollution levy is associated with a decrease of about 1% in the expected number of firms in the high polluting industries and with a drop of 0.3% in the medium polluting industries, holding all other factors constant.

The coefficients vary slightly in magnitude when the city and industry fixed effects are introduced, although the results of the pollution haven effect generally hold. Both the *volume effect* and the *composition effect* of the pollution levy are larger in the models with city and industry fixed effects. However, a negative overall effect of the pollution levy can still be observed in polluting industries. According to the model with both the city and industry fixed effects, for example, a 10% increase in the effective pollution levy is correlated with a 1.18% decrease in total output of the most polluting industry within a city and a 0.1% drop in the number of firms in the polluting industry within each industry and each city.

Thus, the preliminary estimates show that both the total output and the number of

³As the effect of the levy in the high pollution industry enters both the coefficient of the $\ln\text{Levy}$ variable and the $\text{High Pol} \times \ln\text{Levy}$ interaction in the model, the average effect of pollution levy in a high polluting industry should be interpreted by adding the coefficient of the pollution levy in all industries and the coefficient of the interaction term.

firms are negatively correlated with the pollution levy in the high polluting and medium polluting industries, confirming the existence of a pollution haven effect.

The coefficients of other control variables are mostly in line with the predictions of the New Economic Geography model. The market potential of a city - measured by the sum of distance-normalized provincial GDP - is positively correlated with the production activities of firms, except for in models where the city fixed effects are controlled for, since the city fixed effects absorb the variation in the market potential index. The total income in a province is positively and significantly correlated with production activities. The estimates suggest that firms are indeed attracted to higher market opportunities in high-income regions.

Production costs are also an important element in the location of industrial activities. Wage is negatively associated with the number of firms in a region, but positively correlated with the total amount of output. The ratio of skilled labor in a region has positive correlation with production activities, while the ratio of unskilled labor has an ambiguous effect on output and number of firms. The price index of fixed assets is negatively correlated with production and the number of firms in the baseline estimation, however, the negative effect is absorbed when the city fixed effects are included. Infrastructure also plays a role in production activities - railway and telephone densities are positively correlated with production activities, although highway density shows a more ambiguous effect. The average total factor productivity per industry and city is also positively and significantly correlated with the amount of output. Finally, having the status of a Special Economic Zone has an important effect in boosting production and increasing the number of firms.

6 A model of regulation and productivity

In this section, I describe a simple general equilibrium model where innovation may alleviate or even completely offset the costs of environmental regulations (Mohr, 2002). I then discuss two environmental policy instruments - the pollution levy and technical regulations - and their effect on productivity.

Assume an economy with perfect information and a constant population consisting of N agents. The market is perfectly competitive. To begin with, all producers in the economy use the same technology. Later I extend the model to allow for the possibility of an additional new technology.

Each agent is endowed with l_i unit of labor per period of time. Aggregated labor supply

is $L = \sum_{i=1}^N l_i$. The agent devotes this labor to the production of a single consumption good c_i . The output of c_i depends on the input of l_i and a cumulative capital k_i specific to the technology. I define k_i by integrating the amount of labor l_i over time τ , from 0 to t . As such, an agent's capital is the accumulation of its labor dedicated to the use of a technology over time.⁴

$$k_{it} = \int_0^t l_{i\tau} d\tau \quad (8)$$

The economy features an environmental externality: the production of c_i generates waste w_i , an environmentally harmful byproduct. Producers do not incur any private cost for generating waste. In the case where only one technology exists, per-capita output per time period is determined by

$$c_{it} = f(l_{it}, w_{it}, k_{it}) \quad (9)$$

where t denotes time. The individual and time subscripts are omitted in the following discussion for the sake of simplicity.

Furthermore, I assume that the production has diminishing returns to scale, in the sense that $df/dl > 0$, $d^2f/dl^2 < 0$; and $df/dk > 0$, $d^2f/dk^2 < 0$. In addition, suppose that $df/dw > 0$ as w approaches zero, and $d^2f/dw^2 < 0$. For a given amount of input l and k , the marginal product of waste reaches zero at some finite maximum level of waste, \bar{w} . If $w = \bar{w}$, then $df/dw = 0$.

Individual utility depends positively on consumption c and negatively on aggregate waste W , where $W = \sum_{i=1}^N w_i$. The infinitely lived agents discount future consumption using a discount factor β . Therefore, at time t , the utility for an individual is

$$u = \int_t^\infty \beta^{(\tau-t)} (c_\tau - \gamma W_\tau) d\tau \quad (10)$$

where γ is a parameter indicating the marginal disutility of waste. I assume that N is large enough so that no agent can measurably change the total amount of waste. Therefore, each individual treats waste as if it were exogenous.

The optimal amount of waste w for the economy should be at a point where the marginal disutility of environmental degradation equals the marginal utility of increased consumption. Therefore, at every period, the optimal amount of pollution is determined by:

⁴Alternatively, the cumulative capital can also be thought of as the sum of investment dedicated to a technology over time. i.e. $k_t = \int_0^t i_\tau dt$; where i_τ denotes investment at time τ

$$\frac{df}{dw} = N\gamma \quad (11)$$

However, the individual agent does not take into account the degree to which its output reduces environmental quality. Therefore, without any government intervention, the agent produces until the marginal product of waste reaches zero. The market equilibrium results in $df/dw = 0$ and $w = \bar{w}$ in every period.

6.1 New technology

Now I assume that there is a new technology g , which can also be used to produce c . For any given level of inputs, the new technology is more efficient than the old technology. With the same amount of inputs, production using the new technology yields more output:

$$f(l, w, k) < g(l, w, k) \text{ for any given } l, w, k \quad (12)$$

Equation (12) implies that technology g is also “cleaner” than technology f in the sense that, for a given level of labor and capital, it can produce the same amount of output with less waste. To clarify this point, suppose that all agents initially use technology f . I now define a function $b(l, w, k)$ that equals the unit waste the producer could abate without sacrificing output. In other words, the waste abatement b satisfies

$$f(l, w_f, k) = g(l, w_f - b, k) \text{ for any given } l, w, k \quad (13)$$

The subscripts f and g designate the two technologies: the new and the old. From any starting value of w_f , the function b identifies the maximum environmental benefits that can be achieved without imposing any long-term production costs. Alternatively, the new technology g can produce more output with the same amount of l , w and k .

In every period, the agent chooses a technology of production. The total supply of labor L can be divided into the amount of labor for each of the two technologies: $L = \sum l_f + \sum l_g$. Likewise, total waste is the sum of the waste produced by the two technologies at time t . Therefore, $W = \sum w_f + \sum w_g$. For the whole economy, $N = N_f + N_g$.

Capital is divided between the two technologies. Assuming that at time t_s the agent switches from technology f to technology g , the capital used in technology f at time t is $k_{ft} = \int_0^{t_s} l_{f\tau} d\tau$, and the capital dedicated to technology g is $k_{gt} = \int_{t_s}^t l_{g\tau} d\tau$.

Technology switching has short-term costs. In the initial period after g is introduced, the agent has larger cumulated investment in f than in g . There exists some period of time α , such that

$$\text{if } (t - t_s) < \alpha, \text{ then } f(l, w, k) > g(l, w, k) \text{ for any given } l, w \quad (14)$$

In the long-run, the agent accumulates capital in the new technology g , and productivity increases to a higher level.

Figure 1: Output as a function of cumulative capital

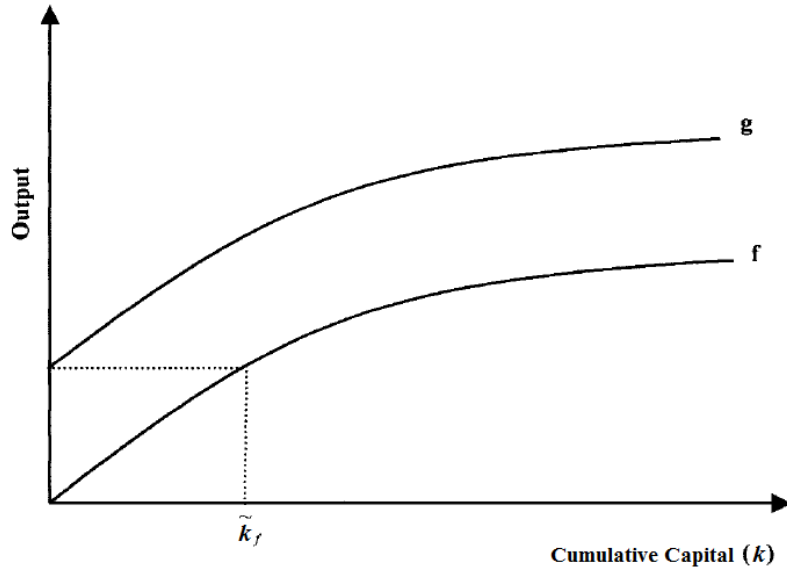


Figure 1 depicts the two technologies and the short-term switching cost. It represents output as a function of cumulative capital k for technologies f and g , with identical levels of l and w . Consistent with equation (12), the curve depicting output for technology g is everywhere above the curve for output using technology f . Furthermore, if the cumulated capital for technology f is greater than \tilde{k}_f , then abandoning technology f and switching to technology g means that output will temporarily decline. This is consistent with equation (14). The productivity increases again when the producer gradually accumulates capital k_g dedicated to the new technology.

Equations (12) and (14) present technical barriers that hinder the application of a new technology. A switch to the new technology results in a short-term decline in productivity due to technology-specific capital accumulation. The fear of short-term productivity loss prevents firms from applying a cleaner and more efficient technology.

6.2 Environmental regulations

Consider a scenario in which the government introduces a regulation that favors or requires the use of a new, clean technology. As a result, agents switch to the new technology, and firms can all increase long-term productivity.

For the society, the optimal level of pollution is decided by equating the marginal social cost of pollution with the marginal benefit of production in every period. Therefore, the government, recognizing that society has t years of experience with technology f , will choose to switch to technology g if:

$$\int_t^\infty \beta^{(\tau-t)} \left(g(l_g, w_g^*, k_{g\tau}) - \gamma W_g^* \right) d\tau > \int_t^\infty \beta^{(\tau-t)} \left(f(l_f, w_f^*, k_{f\tau}) - \gamma W_f^* \right) d\tau \quad (15)$$

where the technology-specific capital depends on cumulative investment in technology f and g respectively, i.e. $k_{f\tau} = \int_0^\tau l_s ds$ and $k_{g\tau} = \int_t^\tau l_s ds$. Note that w_g^* is the level of waste that satisfies equation (11) for technology g , and w_f^* is the level of waste that satisfies equation (11) for technology f .

Alternatively, suppose that the government mandates that producers must reduce waste by some amount ε , where $0 < \varepsilon < b(l, w_f, k)$. This is equivalent to a pollution emission or discharge standard.

Agents who adopt the new technology choose w_g at every point in time to solve the problem:

$$\max \int_t^\infty \beta^{(\tau-t)} \left(g(l_{g\tau}, w_{g\tau}, k_{g\tau}) - \gamma W_{g\tau} \right) d\tau$$

subject to $w_{g\tau} \leq (\bar{w}_f - \varepsilon)$ for all τ (16)

Since producers face no private cost for producing waste, each agent produces the maximum allowable level of waste in every period. Nonetheless, environmental quality improves because $\varepsilon > 0$, and productivity increases in the long-run because $0 < \varepsilon < b(l, w_f, k)$.

Now consider a scenario where, instead of imposing technical standards, the government decides to impose a pollution levy/tax. An optimal levy would equal the marginal disutility of waste γ , thus internalizing the externality of pollution and inducing firms to produce at the socially optimal level of pollution. The levy would reduce emissions, but it would also impose a compliance cost measured in lost productivity. In the presence of a new technology, however, the levy could induce agents to switch to the new, cleaner technology.

Suppose now that the government charges a pollution levy r on waste w . The agent produces until the marginal product of waste equals the levy rate. The agent switches to technology g if the profit (i.e. total output minus the levy payment) using technology g is bigger than the profit using technology f .

$$g(l_g, w_g^*, k_{g\tau}) - rw_g^* > f(l_f, w_f^*, k_{f\tau}) - rw_f^* \quad (17)$$

In the ideal situation where the levy rate equals the social cost of pollution, each agent's decision would equal the socially optimal.

To sum up, the model allows conditions under which a government intervention induces firms to switch to a more efficient technology and thus raises the productivity in the long-run, even though output in the short-run might be compromised. To do so, however, two strong assumptions must hold. First, a more productive but unused technology must be available. Second, environmental policy can only improve productivity if it favors a new technology - one that is cleaner and more efficient. Although I cannot fully describe the time paths for waste and output without assigning a functional form to f or g , the model does show that Porter's arguments which states that environmental regulations can simultaneously alleviate pollution and benefit productivity is consistent with economic theory.

This model builds on Mohr (2002) but differs from the original model in several ways. First, instead of assuming identical agents, the model imposes no specific restriction on the agents' production function and therefore can be applied to an economy with heterogeneous firms. Secondly, as opposed to the technology spillover effect assumed in Mohr's paper, the model sees the capital as cumulative and technology-specific. The productivity effect of a technology switch would thus be affected by agents' past investment decisions.

Finally, the model extends the analysis to take into account various forms of government interventions, including technological standards and pollution levy. The model predicts that a higher pollution levy can induce firms to adopt new and cleaner technologies, resulting in productivity increase. Government-imposed technological standards can also reduce emission and increase long-term productivity, although productivity can decline temporarily due to the cost of switching to a new technology. This important extension provides the theoretical background for the subsequent discussion of environmental regulatory measures.

7 Data

The data in the empirical analysis are gathered from two main sources. The firm-level information on industrial enterprises is taken from annual surveys conducted by the Chinese National Bureau of Statistics (NBS). The data used to calculate the pollution levy, industrial pollution intensity and other environment-related variables are collected from the *China Environment Yearbooks* from the years 1998 to 2007. In this section, I describe the source of the data and the calculation of key variables used in the analysis.

7.1 Annual Survey of Industrial Firms

The *Chinese Annual Survey of Industrial Firms* (ASIF) conducted by NBS contains key business and financial information concerning all state-owned enterprises (SOEs) and private enterprises with an annual turnover higher than 5 million RMB. For each firm, the survey reports detailed information concerning its financial and operational characteristics such as total sales, costs, investment, ownership type, etc.

The ASIF data pertains to a large share of the total manufacturing sector in China. The total sales of all sample enterprises in the dataset amount to about 19,560 billion RMB in 2004. Comparatively, the National Economic Census reports total sales of manufacturing enterprises at 21,844.281 billion RMB for the same year. Thus the database covers roughly 90% of total sales in China.

The dataset comprises a total of 2 million observations. The per-year numbers of observations increases from 160,000 in 1998 to 330,000 in 2007. Due to closure, restructuring and the exclusion of small-scale private firms, only 40,184 enterprises (about 10% of the total sample) appear continuously throughout the period studied.

Table 2 summarizes the number of enterprises by ownership type during the 1998-2007 period. The ownership type is defined by the firm's initial source of capital investment. For example, SOEs are those whose majority registered capital (over 51%) is owned by the State; collectively-owned enterprises are those whose majority registered capital (over 51%) is owned by a commune. The percentage of state-owned and collectively-owned enterprises decreased significantly over the ten years studied, dropping from 2/3 of the sample in 1998 to less than 1/10 in 2007. Conversely, the ratio of private enterprises increased rapidly from less than 20% in 1998 to more than 70% at the end of the period.

Table 2: Types of Chinese industrial enterprises by ownership

Year	Total number of Firms	State -owned	Collectively -owned	Private	Foreign -invested	HK, Macao, -invested TW-invested
1998	165,118	60,719	50,934	26,621	17,637	12,400
1999	162,033	54,900	46,479	29,466	17,086	13,151
2000	162,883	46,652	40,376	37,212	16,588	14,132
2001	171,240	40,023	34,823	50,391	17,295	15,443
2002	181,557	34,758	30,769	63,439	19,058	15,930
2003	196,222	28,628	24,637	78,448	20,181	17,913
2004	274,763	27,002	23,822	123,310	28,427	25,400
2005	271,835	21,724	20,476	126,928	29,480	24,604
2006	301,961	19,847	20,061	148,004	32,147	26,136
2007	336,768	13,305	16,431	166,824	32,543	28,357

Notably, the unit of observation in the dataset is a firm, defined as a legal unit in China. In most cases, the enterprises contained in the data are single-plant manufacturing firms. In 1998, for example, 88.9% of the firms reported having a single production plant, 1.4% had two plants, and 2.0% more than two. In 2007, the share of single-plant firms increased to 96.6%. It is important to note that most of the firms in the dataset only have one plant, since the environmental regulations are specific to firms' locations, the potential measurement error arising from multi-location firms is marginal.

7.2 Dependent variable: Total Factor Productivity

The dependent variable in the empirical analysis is the total factor productivity (TFP) of firms, calculated using the Olley and Pakes (1996)(OP) method. The OP method addresses two key problems in firm-level data analysis - simultaneity issue and the selection bias. Simultaneity issue stems from the dynamic relationship of firm productivity and their investment decisions - more productive firms tend to invest more in capital, and thus calculating the productivity based on the observed capital stock could under-estimate the TFP for the most productive firms. The selection bias comes from the fact that less productive firms are likely to exit the market, and counting total factor productivity based only on surviving firms is therefore likely to over-estimate productivity.

The OP method is the most suitable to calculate the firm total factor productivity in the Chinese firm-level dataset because it allows the best use of the large unbalanced data where only a small percentage of firms survive over the entire period. As the OP method takes into account the firm entry and exit, it also avoids an over-estimation of the TFP by only including surviving firms. It is worth noting that there are a few alternative approaches

to estimate firm TFP. For example, Levinsohn and Petrin (2003)(LP) use an intermediate input demand function to reveal productivity. LP consider intermediate inputs such as electricity, fuel, or materials as a “proxy” for unobserved productivity. However, Akerberg et al. (2006) point out that the LP estimation suffers from a collinearity problem in the first stage estimation.

Below I briefly describe the OP method. Olley and Pakes (1996) assume that productivity ω_{it} evolves exogenously following a first-order Markov process. Capital is assumed to be a dynamic input subject to an investment process. In every period, the firm decides on an investment level i_{it} , which adds to future capital stock deterministically. In contrast, labor is a non-dynamic input. A firm’s choice of labor for a period t has no impact on the future profits of the firm.

OP address the simultaneity problem by assuming that a firm’s optimal investment level i_{it} is a strictly increasing function of their current productivity ω_{it} . The investment function can then be inverted to obtain a function of productivity ω_{it} with regards to investment i_{it} and capital k_{it} . OP use this inverse function to control for ω_{it} in the production function. The first stage of OP involves estimating the equation:

$$\begin{aligned} y_{it} &= \beta_k k_{it} + \beta_l l_{it} + f^{-1}(i_{it}, k_{it}) + \epsilon_{it} \\ &= \beta_k k_{it} + \beta_l l_{it} + \phi(i_{it}, k_{it}) + \epsilon_{it} \end{aligned}$$

where y_{it} is the output or value-added of firm i in year t , k_{it} indicates the capital stock, l_{it} is the labor input in production. The second stage of OP proceeds given the estimations of $\hat{\beta}_l$ and $\hat{\phi}_{it}$.

To address the sample selection bias, Olley and Pakes model a firm’s survival probability by assuming that, at each period, a firm compares the sell-off value of its plant to the expected discounted returns of staying in business. If the current state variable indicating continuing operations is not worthwhile, the firm closes down the plant. If not, the firm chooses an optimal investment level (constrained to be non-negative). To identify β_k , OP use estimates of survival probabilities:

$$\begin{aligned} &Pr\left[\chi_{t+1} = 1 \mid \underline{w}_{t+1}(k_{t+1}), I_t\right] \\ &= Pr\left[\omega_{t+1} \geq \underline{w}_{t+1}(k_{t+1}) \mid \underline{w}_{t+1}(k_{t+1}), \omega_t\right] \end{aligned}$$

χ_t equal to 1 indicates the firm survives. From the assumption that k_{it} is decided before the full realization of ω_{it} , one can estimate β_k by minimizing the sample analogue of the deviation of ω_{it} from the expectations in the previous period.

Table 3 reports the estimated share of the production inputs - capital stock and labor - in the OP estimation. The dependent variable is the log of firms' real value-added, defined as the price-deflated RMB value of output minus raw material input. It captures the value a firm creates in the economy. The log of capital stock k_{it} is used as a state variable, and investment i_{it} is used as a proxy for productivity. Log labor l_{it} is used as free variables in the sense that a firm's choice of l_{it} has no impact on the future profits of the firm.

Table 3: Olley-Pakes productivity estimator

	Coefficient	Standard error	p -value
\ln Capital	0.32133	0.003751	0.000
\ln Labor	0.58503	0.001335	0.000
Number of firm-year observations	1314897		
Number of firms	550830		

Productivity estimation using the Olley and Pakes method
Dependent variable: log real value-added; State variable: log capital stock k_{it}
Proxy: log investment i_{it} ; Free variables: log labor l_{it}

Capital stock k_{it} is calculated as the original purchasing value of the fixed capital minus the accumulated depreciation. Since annual investment is not directly observed in the data, I calculate investment i_{it} as the net fixed capital in time t minus the net fixed capital in the pervious period. Labor input l_{it} is calculated as the natural log of the annual wage bill and payment of employment benefits.⁵ All variables are normalized using the input and output price deflators provided in Brandt et al. (2014).

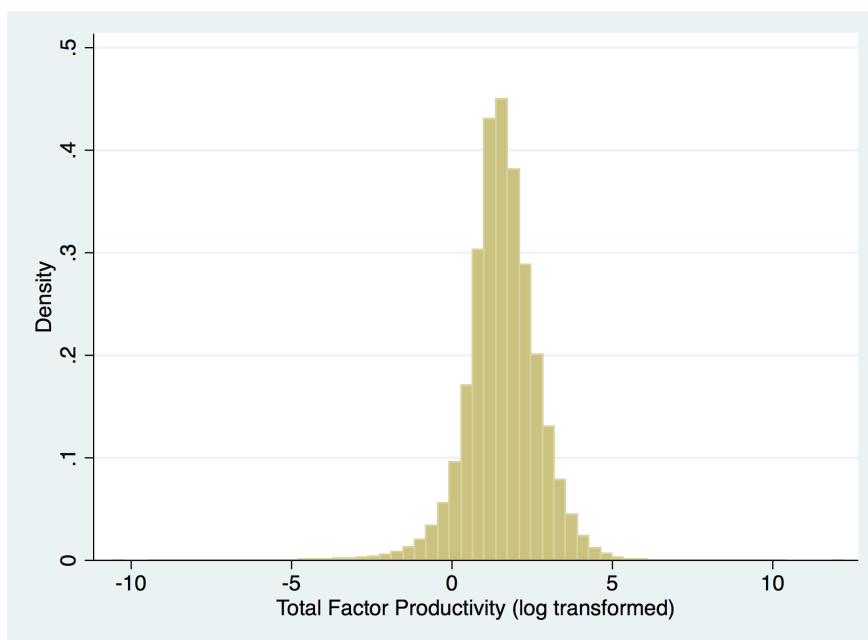
Table 4: Estimated Firm Total Factor Productivity

Variable	Observations	Mean	Std. Dev.	Min	Max
TFP	2,115,466	8.88816	147.3511	0.000026	204612.3
log TFP	2,115,466	1.57996	1.07397	-10.55576	12.22887

After estimating the share of capital and labor inputs in the firm production function, I calculate the total factor productivity as the residual of the firm value added. Table 4 reports the summary statistics of estimated total factor productivity and its logarithm. Figure 2 shows the density distribution of the natural logarithm of the calculated TFP. These estimates are consistent with the literature on Chinese firms' total factor productivity estimations (Guo and Jia, 2005; Brandt et al., 2012; Yang and He, 2014). Table 14 in Appendix D reports the estimated log TFP by industry.

⁵It is common in the literature to use the wages and employment benefit payments to proxy labor input in the calculation of TFP. This measure reflects the labor input in production more accurately than the number of employees.

Figure 2: Log of TFP calculated using Olley and Pakes method



7.3 Effective pollution levy

The *China Environment Yearbooks* report the annual total pollution levy by province, and breaks the total pollution levy down by water pollution, air pollution and solid waste pollution. Although the calculation of the pollution levy is determined by the national pollution levy regulation, in practice, the levy rate varies substantially across different provinces.

I construct the *effective pollution levy* as an indicator of the stringency of environmental regulations in a province. The effective pollution levy rates are calculated as the water and air pollution levy collected in each province every year, divided by the amount of water and air pollution emissions in the corresponding year.⁶

The *effective water levy rate* is calculated as the total water pollution levy divided by the total chemical oxygen demand (COD). COD is the most common water pollutant in China. I divide the provincial pollution levy by the total COD discharge by province to measure the stringency of water levy regulations. For years prior to 2003, the *China Environment Yearbooks* report above-standard pollution levies and wastewater discharge fees separately. I calculate the provincial water pollution levy by adding the two items.

The *effective air levy rate* is calculated as the total air pollution levy divided by the total

⁶For the period between 2003 and 2006, the *China Environment Yearbooks* do not report the breakdown of the pollution levy by pollutants. I construct the water and air pollution levy based on the total pollution levy multiplied by the proportion of water levy over total levy in year 2007 and 2008.

SO₂ emission in the corresponding province. SO₂ is the most common air pollutant in China and a key focus for monitoring and levy collection. For the period before 2003, I calculate the total air pollution levy as the sum of above-standard air pollution levies and the SO₂ emission fee reported in the *China Environment Yearbook*.

To remove the effect of inflation over the years studied, I adjust the effective pollution levy rates by the provincial producer price index (PPI), released by China's National Bureau of Statistics. Table 5 summarizes the *effective pollution levy rate* by year. After adjusting for inflation, the effective pollution levy displays a rising trend over time. The water pollution levy per unit of pollutant is consistently higher than the air pollution levy.

Figure 3 plots the average provincial effective pollution levy on a map of China. Darker colors indicate higher effective levy rates. With the exception of the Tibet Autonomous Region, the effective pollution levy rate is correlated with income levels in most provinces - coastal regions in China, which are more economically developed, tend to charge higher effective pollution levies.

Table 5: Effective water and air pollution levy rate
(RMB / kilogram of pollution emission)

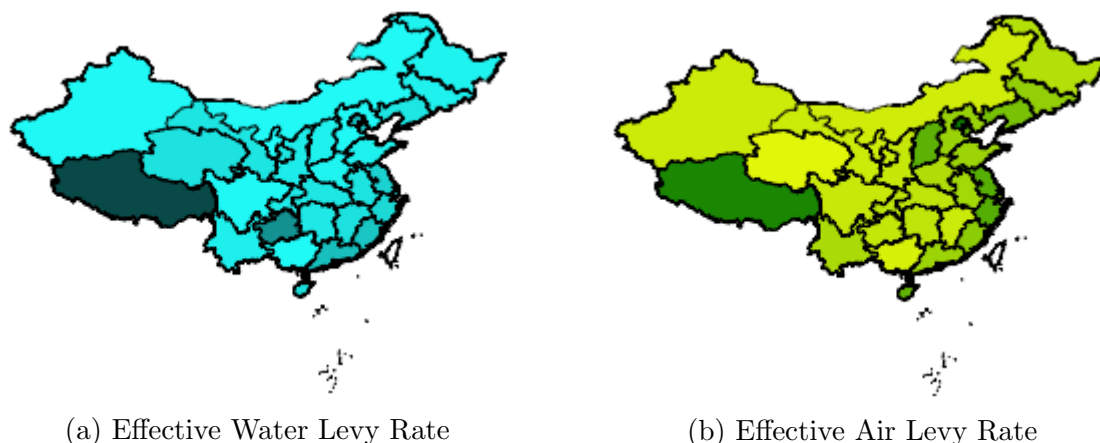
Year	Effective Water Levy Rate					Effective Air Levy Rate				
	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max
1998	30	0.3143	0.2016	0.0636	0.8725	30	0.0839	0.0524	0.0156	0.2228
1999	30	0.3619	0.2506	0.0632	1.2030	30	0.1198	0.0777	0.0134	0.3658
2000	30	0.4045	0.3025	0.0148	1.5067	30	0.1037	0.0619	0.0150	0.2696
2001	31	0.4730	0.3132	0.0874	1.3956	30	0.1441	0.1409	0.0227	0.8164
2002	30	0.5637	0.3742	0.1310	1.6778	30	0.1695	0.2195	0.0301	1.2727
2003	31	0.6178	0.5208	0.0539	2.4243	31	0.2132	0.1486	0.0553	0.8637
2004	31	0.5972	0.5529	0.0441	2.2679	31	0.3766	0.2370	0.0701	1.1048
2005	31	0.6842	0.8278	0.0713	3.7088	31	0.4344	0.3164	0.0779	1.5598
2006	31	0.8695	1.1982	0.0681	5.4640	31	0.4795	0.3316	0.0651	1.3225
2007	31	1.0271	1.3582	0.0812	6.7528	31	0.5278	0.3730	0.0224	1.4864
2008	31	0.9000	1.1614	0.0745	5.1387	31	0.5175	0.3226	0.1257	1.4005

Note: The effective pollution levy rates are calculated as the total water and air pollution levies collected in each province each year, normalized by the COD and SO₂ emissions. The effective levy rates increase over time and varies across provinces.

7.4 Pollution Emission Standards

Emission standards are the maximum allowable concentrations of pollutants in industrial emissions or discharges. China issued the first *Integrated Wastewater Discharge Standard*

Figure 3: Average effective pollution levy rate by province



in 1988 and updated it in 1998. A range of water discharge standards were issued subsequently targeting specific industries. Similarly, China issued the *Integrated Emission Standard for Air Pollutants* in 1996, followed by a range of air pollution emission standards targeting specific industries and sectors. Appendix C.1 lists the national pollution discharge and ambient standards published since 1996.

In addition, local governments can create ambient and discharge standards for pollutants not specified in national standards. They can also establish stricter emission standards than the national standards. As of June 2012, the Chinese Ministry of Environmental Protection recognizes 80 local pollution emission standards published by provincial governments. About 60 of these standards are related to industrial production emissions. These standards target specific industries and usually are more strict than the national standards. Appendix C.2 lists the provincial pollution standards effective as of June 2012.

To quantify the effects of pollution emission standards on productivity, I construct binary indicator variables (sometimes referred to as “dummy” variables) based on the industry-specific national and local pollution emission standards. The variables equal 1 if a national or provincial standard takes effect in an industry in a particular year. I also create lagged variables for the years after a standard is published and put into effect. For the integrated water and air emission standards that apply to all industries nation-wide or in a province, the dummy variable equals 1 in the year when the standards is introduced and the lagged dummies equal 1 for the subsequent years.

7.5 Industry pollution intensity

Environmental regulations, even when applied across all industries, disproportionately affect pollution-intensive firms. I calculate the average industry-level pollution intensity in order to capture the degrees to which industries are affected by the environmental regulations.

The *China Environment Yearbooks* report the pollution emissions by industry according to the 2-digit divisions of Chinese industrial classification, which include 39 sectors covering mining, manufacturing, and energy supply. For each industry, the official statistics report the amount of emissions of major pollutants, such as chemical oxygen demand (COD), total suspended solids (TSS), ammonia nitrogen for wastewater, and sulfur dioxide (SO₂), nitrogen oxides (NO_x), industrial soot and dust for air pollutants. To make meaningful comparisons across pollutants, I convert all water pollutants into COD equivalents and all air pollutants into SO₂ equivalents using the conversion parameters published in official Chinese regulations. The industry-level pollution emissions are then normalized by the output per industry. I deflate the industry output by the industry-specific producer price index (PPI) in order to remove the inflation effects.⁷

Prior to 2002, Chinese industrial data were classified using GB/T 4754-1994 standard. From 2002 onward, industrial data have been classified using a new GB/T 4754-2002 standard. The new industrial classification standard has more divisions compared with the one used before 2001. The emissions and output data published from 1998 to 2000 has several industrial divisions grouped together.⁸ To make meaningful comparisons of industrial pollution across years, I disaggregate these grouped data from 1998 to 2000 to match with the industrial classification used in 2001 onwards.⁹

Appendix E lists the industrial pollution intensity by measure of COD and SO₂ equivalent pollution emissions. Overall, China's industrial pollution intensity has decreased over the years studied.

⁷The data of producer price index come from two main sources: for all manufacturing sectors, I use the Chinese industry output deflator developed and described in Brandt et al. (2014); for all other sectors, including mining and energy, I use the official industry PPI released by the National Bureau of Statistics.

⁸For example, divisions 13 to 16 were grouped as "Food, Beverages and Tobacco", divisions 35 to 41 were grouped as "Machine, Electric Machinery & Electronic Equipment Mfg.", and divisions 44 to 46 were grouped as "Production and Supply of Electric Power, Gas, and Water".

⁹I first create corresponding groups for the years 2001 to 2003 by summing the appropriate division data for each group, and calculate the average share of emissions of each pollutant attributable to a division within the group. I then apply these shares to the grouped data in the early period. Each group's annual emission data from 1998 to 2000 for each pollutant was multiplied by the corresponding average share to derive the missing annual emissions data for each division within that group. I follow a similar procedure to derive the missing output data for each division within each group.

8 Empirical specifications and results

This section explains the empirical models to estimate the effects of pollution levy and emission standards on the productivity of firms. It also reports the estimation results for the two policy measures - the pollution levy and emission standards - respectively.

8.1 Pollution levy

I employ the following estimation model to analyze the effect of pollution levy on productivity.

$$TFP_{ijpt} = \alpha_0 + \beta_1 PI_{jt} \times L_{pt} + \beta_2 PI_{jt} \times (L_{pt})^2 + \beta_3 PI_{jt} \times (L_{pt})^3 + \gamma X_{it} + v_{pt} + v_{jt} + v_{jp} + \varepsilon_{ijpt} \quad (18)$$

the subscripts i, j, p, t represent the firm, industry, province and time. TFP_{ijpt} is the natural logarithm of a firm's total factor productivity, PI_{jt} stands for the pollution intensity of the industry j in year t , L_{pt} is the effective (water and air) pollution levy in province p and in year t . X_{it} is a set of firm-specific control variables. In addition, I include v_{pt} , v_{jt} and v_{jp} to account for the province-by-year, industry-by-year and province-by-industry fixed effects. ε_{ijpt} is the idiosyncratic error term.

The interaction term $PI_{jt} * L_{pt}$ represents the pollution levy intensity. Essentially, a higher pollution levy intensity means that industry j in province p is subject to a higher pollution levy. To test whether firm productivity has a non-linear relationship with regards to environmental regulations as predicted in the model, I also include a square and cubic term of the effective pollution levy in the regressions.

I include the interacting fixed effects to eliminate unobserved factors that can simultaneously affect firm productivity and pollution-control measures. The province-by-year fixed effects control for time-varying provincial factors such as GDP and infrastructure development. The industry-by-year fixed effects control for time-varying changes in an industry such as input and output prices, technological upgrades, etc. The industry-by-province fixed effects account for factors that might affect industry productivity in a particular region.

In some of the estimations, I include firm-specific control variables to account for the effects of different ownership types and firm characteristics on productivity. As widely documented in the literature, firm-level productivity in China varies greatly across ownership types, with private enterprises being the most productive (Hsieh and Klenow, 2007;

Song et al., 2011). Moreover, the size of a firm, the number of years since its establishment, whether the firm exports to foreign markets and the capital-labor ratio could also affect productivity (Syverson, 2011). I include the ownership type, firm size, age, export status and capital-labor ratio to control for the factors likely to affect the productivity of a firm.

The size of a firm is defined by the number of employees. The capital labor ratio is defined as the capital stock divided by the number of employees. The age is the number of years since the firm was established. A binary indicator variable *Foreign* equals 1 if more than 25% of the firm's registered capital is from investors outside of China; *hkmctw* indicates if an enterprise has over 25% of its capital from investors based in Hong Kong, Macao or Taiwan; *S.O.E.* indicates a state-owned enterprise if over 51% of the registered capital is state-owned; variable *Private* equals 1 if over 50% of the firm's registered capital is privately owned; *Exporter* equals 1 if the firm export to a foreign market.

Table 6 reports the estimates for the water and air pollution levy rates. Columns (1) to (3) report the regression results without firm control variables, and columns (4) to (6) report the results with firm-specific control variables. I include the equivalent water and air pollution intensities interacting with the linear, quadratic and cubic forms of the effective pollution levy.

Looking at the water pollution levy first, when excluding firm control variables, the simple interaction of the water pollution levy and industrial pollution intensity is positive and statistically significant at a 10% level. In column (2) the quadratic term of the effective water pollution levy interacting with pollution intensity also displays a statistically significant relationship with productivity at a 5% level. In column (3), I also include the cubic term of the effective water pollution levy, the coefficients of the quadratic term is statistically significant. The results display a similar pattern when control variables are included. The positive coefficient of water levy interacting with pollution intensity is statistically significant a 1% level after controlling for firm characteristics.

The effect of the air pollution levy on total factor productivity suggest a positive correlation. The linear term of the levy interacting with air pollution intensity is positively correlated with productivity. On average, a one-unit increase in the effective pollution levy is associated with an increase of 0.3%-0.5% in total factor productivity. The interaction of industry pollution intensity with the quadratic and cubic terms of the air pollution levy is also significantly correlated with firm productivity.

Based on the estimation results, Appendix A plots the cubic relationship between the pollution levy and TFP. A positive coefficient of the quadratic term and negative coefficients of the linear and cubic terms indicate a bell-shaped relationship between the pollution

Table 6: Water and Air Levy Rate on TFP

	(1)	(2)	(3)	(4)	(5)	(6)
	TFP	TFP	TFP	TFP	TFP	TFP
COD Equivalent Pollution Intensity						
× Water Levy	0.0026* (0.0015)	-0.0011 (0.0022)	-0.0043 (0.0035)	0.0038*** (0.0015)	0.0016 (0.0021)	0.0003 (0.0033)
× Water Levy ²		0.0027** (0.0011)	0.0067* (0.0036)		0.0016 (0.0011)	0.0032 (0.0035)
× Water Levy ³			-0.0009 (0.0007)			-0.0003 (0.0007)
SO ² Equivalent Pollution Intensity						
× Air Levy	0.0054*** (0.0013)	0.0013 (0.0031)	-0.0209*** (0.0046)	0.0035*** (0.0013)	0.0021 (0.0030)	-0.0138*** (0.0044)
× Air Levy ²		0.0034 (0.0024)	0.0504*** (0.0081)		0.0012 (0.0023)	0.0348*** (0.0077)
× Air Levy ³			-0.0252*** (0.0044)			-0.0180*** (0.0042)
S.O.E.				-0.5533*** (0.0029)	-0.5533*** (0.0029)	-0.5533*** (0.0029)
Foreign				-0.0213*** (0.0027)	-0.0213*** (0.0027)	-0.0213*** (0.0027)
Hong Kong, Macao, Taiwan				-0.1211*** (0.0026)	-0.1211*** (0.0026)	-0.1211*** (0.0026)
Private				0.0531*** (0.0016)	0.0531*** (0.0016)	0.0531*** (0.0016)
Size				0.2980*** (0.0108)	0.2980*** (0.0108)	0.2980*** (0.0108)
Exporter				-0.0599*** (0.0020)	-0.0599*** (0.0020)	-0.0599*** (0.0020)
Capital-labor ratio				-0.0000** (0.0000)	-0.0000** (0.0000)	-0.0000** (0.0000)
Age				-0.0145*** (0.0001)	-0.0145*** (0.0001)	-0.0145*** (0.0001)
Province#Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry#Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry#Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2096094	2096094	2096094	2095708	2095708	2095708
R ²	0.1820	0.1820	0.1820	0.2490	0.2490	0.2490
F	9.4435	6.4325	11.6137	11113.4127	9261.6374	7940.1712

Dependent variable: log of firm Total Factor Productivity. Robust standard errors in parentheses.

* significant at the 10 percent level.

** significant at the 5 percent level.

*** significant at the 1 percent level.

levy and firm productivity. As the levy rate increases, TFP first decreases, then increases and then goes down again beyond a certain point. The air pollution levy displays a more clear bell-shaped relationship with productivity. For a pollution levy rate below 0.4 RMB per thousand RMB output,¹⁰ an increase in pollution levy is associated with a decrease in total factor productivity. When the water pollution levy rate is between 0.4 RMB and 1.2 RMB, productivity increases with the pollution levy. And a second turning point appears around 1.2 RMB beyond which productivity decreases with air pollution levy again.

The positive and bell-shaped relationship between water and air pollution levy and productivity may seem paradoxical at first glance. However, the theoretical model discussed in Section 3 presents such a possibility: when the pollution levy is low, firms may opt for paying the pollution levy or for diverting some of their resources towards pollution abatement. When the pollution levy rate is above a certain level, however, firms may find it more profitable to switch to new, cleaner technologies, resulting in both reductions in pollution and increases in productivity.

8.2 Pollution levy - First difference

A potential issue in the analysis can be associated with the possibility that the environmental regulation measures are *endogenously* determined by the productivity of firms. One source of endogeneity can be related to the fact that local authorities can exercise considerable discretion on firm pollution levies. For example, Wang et al. (2003) find evidence that state-owned enterprises have greater bargaining power with local environmental authorities and can thus successfully negotiate lower effective levy rates.

To eliminate potential reverse causality, I estimate the questions in first differences, so that constant industry and firm characteristics, such as ownership type, are differenced out. I also include industry and province dummies to account for unobserved industry trends and regional characteristics. The firm productivity is represented by the following equation:

$$TFP_{ijpt} = \alpha_{jt} + \alpha_{pt} + \beta(PI_{jt} \times L_{pt}) + \mu_i + \varepsilon_{ijpt} \quad (19)$$

where α_{jt} and α_{pt} are time-varying industry and provincial characteristics. PI_{jt} stands for the pollution intensity of the industry j in year t , L_{pt} is the effective (water and air) pollution levy in province p and in year t . $PI_{jt} \times L_{pt}$ therefore represent the amount of pollution levy per industrial output.

¹⁰The unit can be roughly interpreted as pollution levy per thousand RMB output, since the explanatory variable is measured as effective pollution levy (RMB per kg pollution emission) times industry pollution intensity (kg pollution per thousand RMB output).

By taking first difference, I eliminate the time invariant plant and industry heterogeneity:

$$\Delta TFP_{ijp} = \Delta\alpha_j + \Delta\alpha_p + \beta\Delta(PI_j \times L_p) + \Delta\varepsilon_{ijp} \quad (20)$$

Table 7 reports the results of the first difference estimation. Column (1) report regression results including 2-digit industry dummies, column (2) reports estimates including province fixed effects, and column (3) reports results with both industry and province dummies. The change in water pollution levy interaction is positively and significantly correlated with change in total factor productivity across all specifications. A one-unit increase in water levy intensity is associated with an increase of about 0.3%-0.5% in total factor productivity.

Table 7: First Difference of Pollution Levy

	(1)	(2)	(3)	(4)	(5)	(6)
	ΔTFP	ΔTFP	ΔTFP	ΔTFP	ΔTFP	ΔTFP
Δ Water Levy \times	0.0050***	0.0037***	0.0027**	0.0048***	0.0036***	0.0026**
Water Pollution Intensity	(0.0013)	(0.0009)	(0.0010)	(0.0013)	(0.0009)	(0.0010)
Δ Air Levy \times	-0.0019	-0.0013	-0.0012	0.0166**	0.0077	0.0095
Air Pollution Intensity	(0.0018)	(0.0018)	(0.0017)	(0.0058)	(0.0042)	(0.0050)
Δ Air Levy ² \times				-0.0410**	-0.0221**	-0.0262*
Air Pollution Intensity				(0.0136)	(0.0084)	(0.0114)
Δ Air Levy ³ \times				0.0189**	0.0113**	0.0131*
Air Pollution Intensity				(0.0062)	(0.0042)	(0.0053)
Industry FE	Yes		Yes	Yes		Yes
Province FE		Yes	Yes		Yes	Yes
Observations	1507671	1507671	1507671	1507671	1507671	1507671
R ²	0.0009	0.0025	0.0031	0.0010	0.0025	0.0031
F	8.4442	8.2574	4.0957	6.1483	5.0544	3.2183

Dependent variable: First difference of log Total Factor Productivity.

Standard errors are clustered by 3-digit industry, reported in parentheses.

* significant at the 10 percent level.

** significant at the 5 percent level.

*** significant at the 1 percent level.

8.3 Pollution emission standards

In this part of the analysis, I estimate the effects of regulatory pollution emission standards on firm productivity using the following linear model:

$$TFP_{ijpt} = \alpha_{jt} + \alpha_{pt} + \sum_{t=1}^T \beta_t S_{jpt} + \mu_i + \varepsilon_{ijpt} \quad (21)$$

where the subscripts i, j, p, t indicate firm, industry, province and time. TFP_{ijpt} is the natural logarithm of a firm's total factor productivity. S_{jpt} is a set of binary indicator variables that equal 1 if an industry-specific pollution standard is put into effect in industry j by province p during a specific year t . S_{jpt} equals one for all provinces if a nation-wide industry pollution emission standard is introduced in industry j during year t . The indicator variable equals zero otherwise. Lagged binary variables are also included for the years after the standards were introduced to capture the dynamic effect of pollution emission standards.

To control for omitted unobserved variables at the firm and sectoral level, I estimate the equation in first difference to eliminate time-invariant plant and sector heterogeneity. In order to control for time-varying industry and regional trends that might affect productivity and pollution emission standards, I include in the differenced question two-digit industry dummies and province dummies that account for unobserved trends at broad sector levels.

$$\Delta TFP_{ijp} = \Delta\alpha_j + \Delta\alpha_p + \sum_{t=1}^T \beta_t \Delta S_{jp} + \Delta\varepsilon_{ijp} \quad (22)$$

Still, there can still be important differences between provinces that are likely to affect environmental standards. In order to control for these factors, I include in some specifications the following control variables: per capita GDP of the province, the effective water and air pollution levies as indicators of environmental stringencies in the province.

$$\Delta TFP_{ijp} = \Delta\alpha_j + \Delta\alpha_p + \sum_{t=1}^T \beta_t \Delta S_{jp} + \gamma_1 GDP_{pt} + \gamma_2 L_{pt} + \Delta\varepsilon_{ijp} \quad (23)$$

Table 8 reports the effects of industry-specific pollution emission standards. *Standard year 1* equal 1 when an industry pollution standard took effect in a region and *Standard year 2* to *6* indicate the subsequent years after the issuance of an industry pollution standard. Column (1) reports the lagged effects of an industry pollution standard for four years and column (2) reports the lagged effects six years following the adoption of a standard. Since the data cover ten years, the estimation including lagged effects for six years has a smaller sample. Columns (3) and column (4) present the results of the same specifications including the per capita GDP of the province as control. Columns (5) and column (6) report results including both per capita GDP and effective water/air pollution levy by province.

A negative and significant coefficient can be observed in the first year when a regulatory

standard is introduced. The coefficient suggests that the issuance of an industry-specific pollution standard is associated with a decline in the total factor productivity of about 4-10 percentage points for the affected industry in the year when the standard is put into effect. The negative effect gradually declines over the years and turns insignificant the third year following the introduction of the environmental standard. The findings confirm that a pollution emission standard can lead to an initial decline in productivity but the negative effect diminishes in the long run.

Table 8: Water and Air Pollution Standards on TFP

	(1)	(2)	(3)	(4)	(5)	(6)
	ΔTFP	ΔTFP	ΔTFP	ΔTFP	ΔTFP	ΔTFP
Standard $year_1$	-0.0474** (0.0205)	-0.0953** (0.0398)	-0.0428** (0.0211)	-0.0886** (0.0398)	-0.0424** (0.0201)	-0.0883** (0.0396)
Standard $year_2$	-0.0286 (0.0196)	-0.0946* (0.0534)	-0.0231 (0.0214)	-0.0876 (0.0550)	-0.0227 (0.0200)	-0.0858 (0.0538)
Standard $year_3$	-0.0208 (0.0196)	-0.0875 (0.0636)	-0.0165 (0.0191)	-0.0809 (0.0618)	-0.0161 (0.0190)	-0.0793 (0.0607)
Standard $year_4$	-0.0079 (0.0124)	-0.0876 (0.0726)	-0.0046 (0.0133)	-0.0835 (0.0722)	-0.0035 (0.0133)	-0.0819 (0.0714)
Standard $year_5$		-0.0774 (0.0699)		-0.0797 (0.0694)		-0.0780 (0.0688)
Standard $year_6$		-0.0518 (0.0747)		-0.0738 (0.0733)		-0.0729 (0.0728)
GDP per capita			0.0015*** (0.0003)	0.0032*** (0.0007)	0.0029*** (0.0004)	0.0036*** (0.0008)
Water Levy					0.0199*** (0.0069)	0.0211 (0.0150)
Air Levy					-0.0590*** (0.0108)	-0.0702*** (0.0216)
2-digit industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	544973	257307	544973	257307	544828	257307
R^2	0.0028	0.0034	0.0029	0.0037	0.0030	0.0037
F	3.1322	3.5424	14.3701	8.3780	15.7573	7.8169

Dependent variable is first difference of total factor productivity of a firm. Standard errors are clustered by 3-digit industry and reported in parentheses.

* significant at the 10 percent level.

** significant at the 5 percent level.

*** significant at the 1 percent level.

8.4 Endogeneity

The analysis assumes that environmental policies are *exogenously* imposed. A potential issue in the analysis can be associated with the possibility that the environmental regulation measures are *endogenously* determined by the productivity of firms. Firm productivity might therefore be a reason, rather than a result, of the pollution levy it is subject to. However, as the pollution levy rate is calculated at the provincial-level while total factor productivity is calculated at the firm-level, endogeneity is less of a concern in the current study. It would be difficult to argue that the overall productivity of all polluting firms in a province would affect the province-wide effective pollution levy.

Another possible source of endogeneity can come from unobserved variables that affect both firm productivity and the pollution levy. For example, one might expect that in high-income provinces, firms tend to be more productive and that pollution levies charged tend to be higher. Out of such concern, I include in the empirical models various fixed effects to account for factors associated with time-variant effects of location and industry. The rich fixed effects included in the estimation should largely eliminate any unobserved factors that affect environmental policy and productivity simultaneously.

9 Conclusions

This paper investigates the effects of two important environmental policy instruments - the pollution levy and regulatory standards - on firm productivity in China. It finds evidence in support of the Porter hypothesis that an increase in environmental standards can actually improve competitiveness under certain circumstances.

The analysis is informed by a theoretical model where a technological upgrade simultaneously alleviates pollution and benefits productivity. Without government intervention, however, firms may be reluctant to upgrade to the new technology due to the switching costs. The model predicts that tighter environmental regulations can induce firms to upgrade technology, leading to productivity increase in the long-run. The model shows Porter's argument that environmental regulations can simultaneously reduce pollution and benefit productivity is consistent with economic theory.

To empirically test the hypothesis, I calculate total factor productivity of Chinese industrial firms based on data from the annual survey of industrial enterprises covering 90% of China's total manufacturing sales over ten years. I also construct policy indicators for the provincial-level effective pollution levy, industry pollution intensity and pollution emission standards based on the statistics published in the *China Environment Yearbooks*. The

calculated effective pollution levy rates range from 0.01 RMB to 6.7 RMB per kilogram of water pollution discharges, and from 0.015 RMB to 1.5 RMB per kilogram of air pollution emissions; significant variations can be observed across provinces and over time.

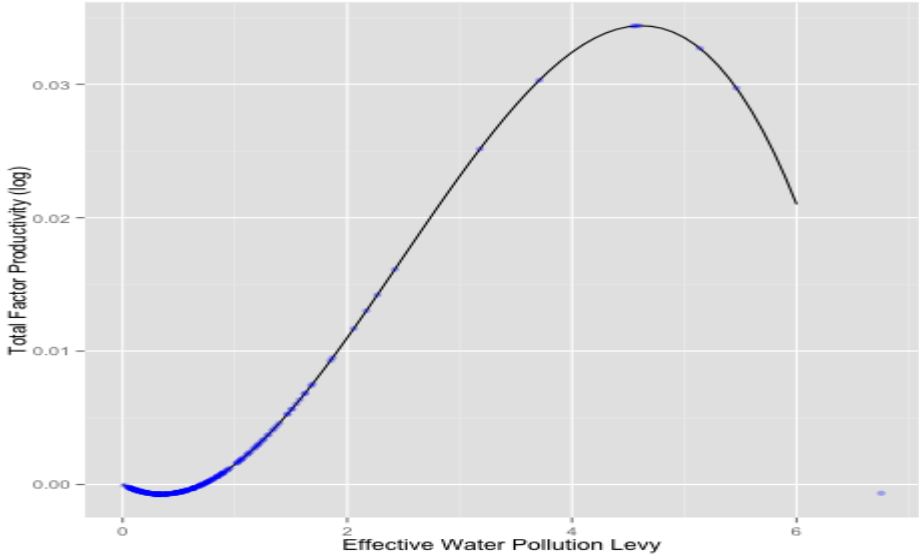
The empirical analysis of the relationship between the effective pollution levy and firm productivity finds a positive or non-linear correlation for the water levy. In some of the estimations, productivity increases with the pollution levy when the levy rate is below 3.5 RMB for roughly per thousand RMB output, and decreases when the pollution levy rate exceeds 3.5 RMB. For the air pollution levy, one can observe a negative correlation between the levy rate and productivity. On average, a one-unit increase in the pollution levy is associated with a drop of 0.6% in total factor productivity.

An analysis of China's regulatory standards finds that emission standards have a negative initial effect on firm productivity but a positive effect in the long-run. An industry-specific pollution standard can be associated with a 2-4% reduction in productivity in the same year that the standard is adopted. The negative effects can last up to three years, but higher environmental standards eventually diminishes and are sometimes correlated with higher productivity. The finding is consistent with the Porter hypothesis whereby environmental standards can induce firms to upgrade technology and increase productivity.

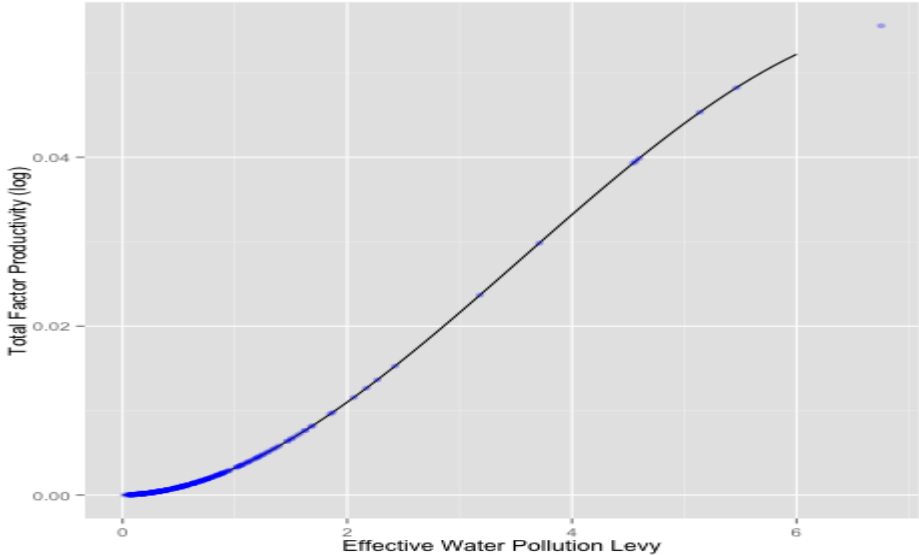
The empirical study in this paper focuses on the correlation, not causality, between pollution control policies and productivity. However, as provincial-level pollution levies and industry-specific pollution emission standards are not likely to be affected by the productivity of individual firms, the policy measures discussed in the study can be thought of as largely exogenous.

The empirical analysis in this paper finds evidence in support of the Porter hypothesis. While similar studies conducted in industrialized countries often find negative correlation between environmental regulations and productivity, the discovery of a positive or sometimes non-linear relationship between pollution control measures and productivity in China suggests that environmental regulations can be associated with productivity increases. As firms in a developing country like China tend to rely on low production technologies, they are more likely to switch to cleaner and more efficient technologies in response to stringent environmental regulations.

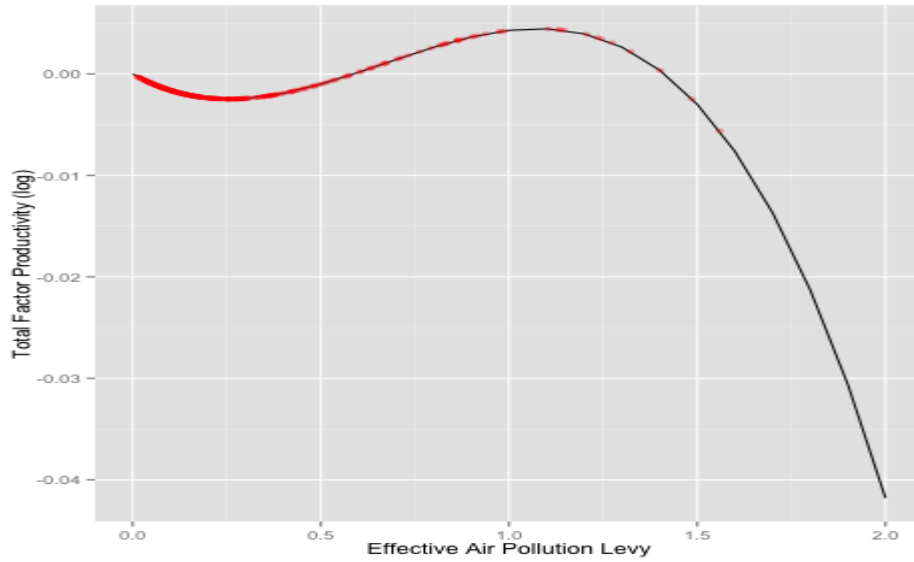
Appendix A - Correlation of pollution levy and TFP



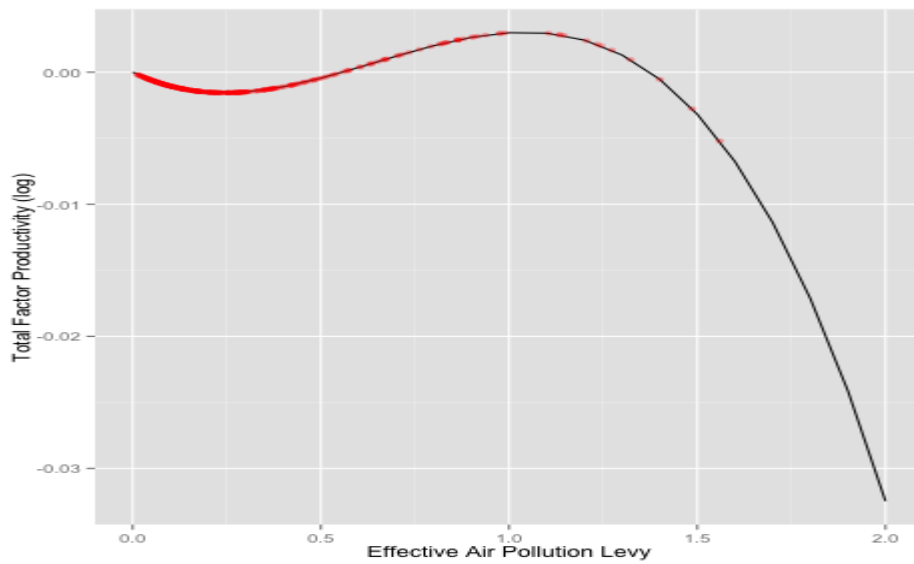
Estimated relationship of water levy and productivity excluding control variables. The blue dots are the actual effective pollution levy rates.



Estimated relationship of water levy and productivity including control variables. The blue dots are the actual effective pollution levy rates.



Estimated relationship of air levy and productivity excluding control variables. The red dots are the actual effective pollution levy rates.



Estimated relationship of air levy and productivity including control variables. The red dots are the actual effective pollution levy rates.

Appendix B - The pollution levy system in China

This Appendix summarizes China's pollution levy system, and in particular, a regulatory change introduced in 2003. Most of the contents are summarized from Wang and Wheeler (2005) and Jin and Lin (2014).

Discussion of a possible pollution charge system began in China after the 1972 Stockholm Conference on the Human Environment. In February 1982, the Central Government of China issued an *Interim Procedure on Pollution Charges* that defined the system's objectives, principles, levy standards, levy collection methods, and the principles for how funds collected through the levy should be used. Nationwide, the implementation of the national levy procedure followed rapidly. In January 2003, the State Council of China passed a new pollution levy regulation which replaced the *Interim Procedure*. The new regulation substantially reformed the pollution levy system.

The pollution levy system is based on universal self-reporting, with verification conducted by local regulatory authorities. At the beginning of the year, plants must register with environmental authorities by providing basic economic information and their expected volume of emissions for the coming year. Environmental authorities verify the registration reports and then issue pollution discharge licenses to plants. During the year, plants are required to modify their reports if their actual emissions are different from those predicted at the beginning of the year. Environmental authorities verify plant reports by conducting field inspections, in most cases without prior warning. At the end of each quarter, based on plant reports and inspections, authorities announce the pollution levies that plants should pay at the end of the quarter. False reporting caught by the authorities is subject to penalties.

Pollution charges are levied for 29 water pollutants and 22 air pollutants, as well as for solid waste and radioactive waste and noise. Among the pollutants, the major focus of monitoring and levy collection is on COD (chemical oxygen demand) and TSS (total suspended solids) for water, and SO₂ and flue dust for the air.

Pre-2003 pollution levy system

The evolution of China's pollution levy system can be divided into two distinct periods: pre- and post-2003. Table 9 summarizes the composition of the levy collections in China from 1992 to 2002.

Prior to 2003, water pollution charges contributed the largest share of the total pollution levies. The water pollution levy charge varies by both the concentration of hazardous

chemicals and the volume of wastewater.

Table 9: Pollution levy collection in China, 1992-2002
(10 000 RMB)

Year	Total	From Emissions above standards					From wastewater discharge fee	From penalties	From SO2 fee
		Water	Air	Solid waste	Noise	Radioactive wastes			
1992	239,452	118,673	50,859	3,079	8,930	1,037	8,485	48,389	
1993	268,013	122,838	56,021	3,747	11,930	20	12,637	60,821	
1994	309,757	132,197	64,498	3,199	15,551	89	20,046	74,177	
1995	371,281	150,365	74,297	4,846	19,019	166	25,384	97,204	
1996	409,594	155,135	67,212	3,743	21,413	183	28,791	118,542	14,575
1997	454,332	164,194	67,682	5,015	24,417	151	30,521	139,799	22,553
1998	490,194	163,746	65,491	4,394	26,410	77	28,281	150,285	51,510
1999	554,512	166,521	69,757	5,956	30,549	383	29,089	166,124	86,133
2000	579,607	172,217	76,104	6,998	34,234	472	27,320	184,658	77,603
2001	621,802	175,803	72,052	8,592	34,864	139	23,521	196,475	110,358
2002	674,376	179,524	79,063	8,983	37,539	252	27,920	218,673	122,424

For a plant i that discharges within the pre-specified concentration standards, the levy for wastewater discharge is based on the total volume of wastewater discharge W and the levy rate R_0 . For within-standard polluters, the uniform levy rate is set at 0.05 RMB per ton of wastewater discharge:

$$L_i = R_0 W_i \quad (24)$$

whereas for a plant that exceeds the concentrate standards, the levy formula for wastewater discharges is:

$$P_{ij} = W_i \frac{C_{ij} - C_{sj}}{C_{sj}}$$

$$L_{ij} = \begin{cases} L_{0j} + R_{1j} P_{ij} & \text{if } P_{ij} > T_j \\ R_{2j} P_{ij} & \text{if } P_{ij} < T_j \end{cases} \quad (25)$$

where for plant i and pollutant j ,

$$\begin{aligned} P_{ij} &= \text{Discharge factor} & W_i &= \text{Total wastewater discharge} \\ C_{ij} &= \text{Pollution concentration} & C_{sj} &= \text{Concentration standard} \\ L_{ij} &= \text{Total levy} & L_{0j} &= \text{Fixed payment factor} \\ T_j &= \text{Regulatory threshold parameter} \end{aligned}$$

R_1 and R_2 are pollution levy charge standards with $R_2 > R_1$; and for continuity at T_j , $R_{2j}T_j = L_{0j} + R_{1j}T_j$. The pollutant concentration standard C_s is jointly set by the

central and local governments. The charge rate R is determined relative to a critical factor T ; both R and T are set by the central government and vary by pollutant, but not by industry. The potential levy L_j is calculated for each pollutant; the actual levy is the greatest of the potential levies.

Table 10 lists the national standards on the pollution levy rates R , threshold parameters T and fixed payment L_{0j} for the most common water pollutants¹¹.

Table 10: Pollution charge standards for common water pollutants

Pollutant	Regulatory Threshold T_j	Levy Charge Standard R_2 (RMB/tons)	Levy Charge Standard R_1 (RMB/tons)	Fixed Payment Factor L_{0j} (RMB)
COD	20000	0.18	0.05	2600
TSS	800000	0.03	0.01	16000
Mercury	2000	2.00	1.00	2000
Cadmium	3000	1.00	0.15	2550
Petroleum	25000	0.20	0.06	3500
Ammonia Nitrogen	25000	0.10	0.03	1750
Hexavalent Chrome	150000	0.09	0.02	10500
Arsenic	150000	0.09	0.02	10500
Lead	150000	0.08	0.03	7500
Volatile Hydroxybenzene	250000	0.06	0.03	7500
Cyanide	250000	0.07	0.04	7500
Sulfide	250000	0.05	0.02	7500

The levy formula for air pollution is

$$L_{ij} = \text{Max} \left[0, R_j V_i (C_{ij} - C_{sj}) \right] \quad (26)$$

where, for plant i and pollutant j , R_j is the charge rate for pollutant j , V_i the total volume of air emissions, C_{ij} the pollution concentration, C_{sj} the concentration standard, L_{ij} the total levy. The charge is zero when the pollutant concentration C is less than or equal to the standard C_s . Unlike the water levy, the air levy is assessed on the absolute, rather than percentage, deviation from the concentration standard. Again, a firm is assessed only by the highest of its potential levies.

There are four major sources of provincial variation in pollution tax rates. First, as noted above, concentration standards C_{sj} are set jointly by the national and local governments and can vary by region. Second, the standard differs by pollutant, thus differences in the concentration of industries across provinces will lead to different effective levy rates.

¹¹NEPA, SPB, and MOF (National Environmental Protection Agency, State Price Bureau and Ministry of Finance), 1991, *A Notice on Adjustment of the Pollution Discharge Fee Rate for Wastewater and the Pollution Levy Rate for Noise*. Document 262-91, Beijing.

Third, there are significant differences in enforcement capacity at the local level. Finally, the levy can be reduced or even eliminated at the discretion of local regulators after appropriate inspection. Such leeway introduces considerable variation into regional enforcement practices.

The pre-2003 levy system has been greatly criticized. It lacks incentives or even provides disincentives to pollution control and abatement because of the decreasing block levy rates for water pollutants. In the case of air pollution, the levy is not applicable to firms that emit below the concentration standard. Furthermore, as the constant rates are not adjusted for inflation, the real value of the pollution levy in later years was substantially lower than in the early years.

Post-2003 pollution levy regulations

In January 2003, the State Council of China passed a new pollution levy regulation, the *Administrative Regulations on Pollution Discharge Levy* (State Council, 2003 Order No. 369). The new regulation expanded the basis of the pollution charge and raised the marginal charge rate. The new levy policy, which took effect on 1 July 2003, resulted in a sharp increase in the total pollution levy.

Table 11 reports the total pollution levy collections from 2003 to 2008. Due to the regulatory change, the *China Environment Yearbook* did not report the breakdown of the levy by type of pollutants between 2003 and 2006.

Table 11: Pollution levy collection in China, 2003-2008
(10 000 RMB)

Year	Total levy	Wastewater	Air pollution	Noise	Hazardous waste
2003	708,975.3				
	<i>Jan-Jun 2003</i>	413,183.0			
	<i>July-Dec 2003</i>	295,471.9			
2004	941,845.8				
2005	1231,586.7				
2006	1441,443.5				
2007	1,735,957.0	361,355.9	1,314,429.0	93,432.7	28,365.3
2008	1,852,368.0	300,736.0	1,411,742.0	92,828.0	11,806.3

The new levy system calls for two steps to calculate the levy amount. The first step is to convert discharge into either COD equivalent for water pollutants or SO₂ equivalent for air pollutants. For both water and air pollution, the formula to calculate the equivalent

pollution is:

$$E_{ij} = \frac{P_{ij}}{F_j} \quad (27)$$

where E_{ij} is the equivalent discharge for pollutant j ; P_{ij} is the emission/discharge of pollutant j in plant i , and F_j is a conversion parameter for pollutant j . The equivalent discharge for each pollutant j is calculated as the plant i 's total emission of pollutant j (in kg) divided by the conversion parameter F_j . The pollutants that are more likely to cause environmental damage are assigned a smaller conversion parameter and have greater amount of the equivalents.

The new formula suggests that any polluter needs to pay for pollution discharge, regardless if their emission meets the concentration standard. Table 12 lists the conversion parameter F_j for selected water and air pollutants.

Table 12: Pollution conversion parameter for selected pollutants

Pollutant	conversion parameter F_j (kg)
<i>Water pollutants:</i>	
COD	1
TSS	4
Petroleum	0.1
Ammonia Nitrogen	0.8
Mercury	0.0005
Cadmium	0.005
Hexavalent Chrome	0.02
Arsenic	0.02
Lead	0.025
Volatile Hydroxybenzene	0.08
Cyanide	0.05
Sulfide	0.125
<i>Air pollutants:</i>	
SO ₂	0.95
NO _x	0.95
CO	16.7
Chlorine	0.34
Dust	4
Soot	2.18

Under the new pollution levy regulation, plants are required to pay levies on the sum of the highest three of the calculated pollution equivalents. The second step to calculate the pollution levy is:

$$L_i = R_j * \sum_{j=1}^3 E_{ij} \quad (28)$$

where R_j is the marginal levy rate, and the total pollution levy L_i is for plant i will

be the marginal levy rate multiplying the sum of the three highest calculated potential charges.

For water pollutants, the marginal levy rate R_j equals 0.7 RMB per unit of COD equivalent, and for air pollutants, the marginal levy rate is 0.6 RMB per unit of SO₂ equivalent for the within-standard discharge. The rates are doubled for discharges that are higher than the standards, i.e. 1.4 RMB and 1.2 RMB for COD and SO₂ equivalent, respectively.

To illustrate the difference between the pre- and post-2003 levy systems, I assume there are two plants, each emitting a total of 500,000 tons of wastewater with three particular pollutants: COD, TSS and Ammonia Nitrogen. One plant emits within the standards and the other exceeds the standards. Table 13 shows the potential levy charge under the pre- and post-2003 regulations. For the within-standard polluter, the levy under the new pollution regulation increased slightly. For the above-standard polluter, the levy under the new regulation is almost five times the levy under the pre-2003 regulations. The comparisons show that the post-2003 system penalizes heavy polluters substantially more.

Table 13: Comparison of potential levy under different pollution levy regulations

	Actual Concentration (mg/L)	Concentration Standard (mg/L)	Pollutant Discharge (kg)	Levy Amount	
				Pre-2003 (RMB)	Post-2003 (RMB)
<i>Within-standard polluter:</i>					
COD	50	100	25,000		17,500
TSS	50	70	25,000		4,375
Ammonia Nitrogen	10	30	5,000		4,375
Total actual levy (RMB)				25,000	26,250
<i>Above-standard polluter:</i>					
COD	200	100	100,000	27,600	103,500
TSS	350	70	175,000	36,000	55,125
Ammonia Nitrogen	50	30	25,000	2,500	21,875
Total actual levy (RMB)				36,000	180,600

Appendix C.2 - National pollution emission standards

Doc No.	Document Title	Pollutant	Publication Date	Effective Date
GB 3095-1996	Ambient air quality standards	air	8-Jan-1996	1-Oct-1996
GB 16171-1996	Emission standard of air pollutants for coke oven	air	7-Mar-1996	1-Jan-1997
GB 16297-1996	Integrated emission standard of air pollutants	air	12-Apr-1996	1-Jan-1997
GB 9078-1996	Emission standard of air pollutants for industrial kiln and furnace	air	7-Mar-1996	1-Jan-1997
GB 8978-1996	Integrated wastewater discharge standard	water	4-Oct-1996	1-Jan-1998
GB 3097-1997	Sea water quality standard	water	3-Dec-1997	1-Jul-1998
GB 13271-2001	Emission standard of air pollutants for coal-burning oil-burning gas-fired boilers	air	12-Nov-2001	1-Jan-2002
GB 13458-2001	Discharge standard of water pollutants for ammonia industry	water	12-Nov-2001	1-Jan-2002
GB 18483-2001	Emission standard of cooking fume (on trial)	air	12-Nov-2001	1-Jan-2002
GB 18486-2001	Standard for pollution control of sewage marine disposal engineering	water	12-Nov-2001	1-Jan-2002
GB 3544-2001	Discharge standard of water pollutants for paper industry	water	12-Nov-2001	1-Jan-2002
GB 3838-2002	Environmental quality standards for surface water	water	28-Apr-2002	1-Jun-2002
GB 18596-2001	Discharge standard of pollutants for livestock and poultry breeding	water	28-Dec-2001	1-Jan-2003
GB 14470.1-2002	Discharge standard for water pollutants from ordnance industry - Powder and explosive	water	8-Nov-2002	1-Jul-2003
GB 14470.2-2002	Discharge standard for water pollutants from ordnance industry - Initiating explosive material and relative composition	water	8-Nov-2002	1-Jul-2003
GB 14470.3-2002	Discharge standard for water pollutants from ordnance industry - Ammunition loading	water	8-Nov-2002	1-Jul-2003
GB 18918-2002	Discharge standard of pollutants for municipal wastewater treatment plant	water	24-Dec-2002	1-Jul-2003
GB 13223-2003	Emission standard of air pollutants for thermal power plants	air	30-Dec-2003	1-Jan-2004
GB 19430-2004	Discharge standard of pollutants for citric acid industry	water	18-Jan-2004	1-Apr-2004
GB 19431-2004	Discharge standard of pollutants for monosodium glutamate industry	water	18-Jan-2004	1-Apr-2004
GB 4915-2004	Emission standard of air pollutants for cement industry	air	15-Dec-2004	1-Jan-2005
GB 18466-2005	Discharge standard of water pollutants for medical organization	water	27-Jul-2005	1-Jan-2006
GB 19821-2005	Discharge standard of pollutants for beer industry	water	18-Jul-2005	1-Jan-2006
GB 20426-2006	Emission standard for pollutants from coal industry	water, air	1-Sep-2006	1-Oct-2006
GB 20425-2006	Discharge standard of water pollutants for sapogenin industry	water	1-Sep-2006	1-Jan-2007

Doc No.	Doc Title	Pollutant	Publication Date	Effective Date
GB 20950-2007	Emission standard of air pollutant for bulk gasoline terminals	air	22-Jun-2007	1-Aug-2007
GB 20951-2007	Emission standard of air pollutant for gasoline transport	air	22-Jun-2007	1-Aug-2007
GB 20952-2007	Emission standard of air pollutant for gasoline filling stations	air	22-Jun-2007	1-Aug-2007
GB 21522-2008	Emission Standard of Coalbed Methane/Coal Mine Gas (on trial)	air	2-Apr-2008	1-Jul-2008
GB 21523-2008	Effluent Standards of Pollutants for Heterocyclic Pesticides Industry	water	2-Apr-2008	1-Jul-2008
GB 21900-2008	Emission standard of pollutants for electroplating	water, air	25-Jun-2008	1-Aug-2008
GB 21901-2008	Discharge standard of water pollutants for down industry	water	25-Jun-2008	1-Aug-2008
GB 21902-2008	Emission standard of pollutants for synthetic leather and artificial leather industry	water, air	25-Jun-2008	1-Aug-2008
GB 21903-2008	Discharge standards of water pollutants for pharmaceutical industry- Fermentation products category	water	25-Jun-2008	1-Aug-2008
GB 21904-2008	Discharge standards of water pollutants for pharmaceutical industry - Chemical synthesis products category	water	25-Jun-2008	1-Aug-2008
GB 21905-2008	Discharge standard of water pollutants for pharmaceutical industry - Extraction products category	water	25-Jun-2008	1-Aug-2008
GB 21906-2008	Discharge standard of water pollutants for pharmaceutical industry - Chinese traditional medicine category	water	25-Jun-2008	1-Aug-2008
GB 21907-2008	Discharge standards of water pollutants for pharmaceutical industry - Bioengineering products category	water	25-Jun-2008	1-Aug-2008
GB 21908-2008	Discharge standards of water pollutants for pharmaceutical industry - Mixed preparation products category	water	25-Jun-2008	1-Aug-2008
GB 21909-2008	Discharge standards of water pollutants for sugar industry	water	25-Jun-2008	1-Aug-2008
GB 3544-2008	Discharge standard of water pollutants for pulp and paper industry	water	25-Jun-2008	1-Aug-2008
GB 25461-2010	Discharge standard of water pollutants for starch industry	water	27-Sep-2010	1-Oct-2010
GB 25462-2010	Discharge standard of water pollutants for yeast industry	water	27-Sep-2010	1-Oct-2010
GB 25463-2010	Discharge standard of water pollutants for printing ink industry	water	27-Sep-2010	1-Oct-2010
GB 25464-2010	Emission standard of pollutants for ceramics industry	water	27-Sep-2010	1-Oct-2010
GB 25464-2010	Emission standard of pollutants for ceramics industry	air	27-Sep-2010	1-Oct-2010
GB 25465-2010	Emission standard of pollutants for aluminium industry	water	27-Sep-2010	1-Oct-2010
GB 25465-2010	Emission standard of pollutants for aluminium industry	air	27-Sep-2010	1-Oct-2010
GB 25466-2010	Emission standard of pollutants for lead and zinc industry	water, air	27-Sep-2010	1-Oct-2010
GB 25467-2010	Emission standard of pollutants for copper, nickel, cobalt industry	water, air	27-Sep-2010	1-Oct-2010

Doc No.	Doc Title	Pollutant	Publication Date	Effective Date
GB 25468-2010	Emission standard of pollutants for magnesium and titanium industry	water, air	27-Sep-2010	1-Oct-2010
GB 26131-2010	Emission standard of pollutants for nitric acid industry	water, air	30-Dec-2010	1-Mar-2011
GB 26132-2010	Emission standard of pollutants for sulphuric acid industry	water, air	30-Dec-2010	1-Mar-2011
GB 15580-2011	Discharge standard of water pollutants for phosphate fertilizer industry	water	2-Apr-2011	1-Oct-2011
GB 26451-2011	Emission Standards of pollutants from rare earths industry	water, air	24-Jan-2011	1-Oct-2011
GB 26452-2011	Discharge standard of pollutants for vanadium Industry	water, air	2-Apr-2011	1-Oct-2011
GB 26453-2011	Emission standard of air pollutants for flat glass industry	air	11-Apr-2011	1-Oct-2011
GB 13223-2011	Emission standard of air pollutants for thermal power plants	air	29-Jul-2011	1-Jan-2012
GB 14470.3-2011	Effluent standards of water pollutants for ammunition loading industry	water	29-Apr-2011	1-Jan-2012
GB 26877-2011	Discharge standard of water pollutants for motor vehicle maintenance and repair	water	2-Jul-2011	1-Jan-2012
GB 27631-2011	Discharge standard of water pollutants for fermentation alcohol and distilled spirits industry	water	27-Oct-2011	1-Jan-2012
GB 27632-2011	Emission standard of pollutants for rubber products industry	water, air	27-Oct-2011	1-Jan-2012
GB 13456-2012	Discharge standard of water pollutants for iron and steel industry	water	27-Jun-2012	1-Oct-2012
GB 16171-2012	Emission standard of pollutants for coking chemical industry	water, air	27-Jun-2012	1-Oct-2012
GB 28661-2012	Emission standard of pollutants for mining and mineral processing industry	water, air	27-Jun-2012	1-Oct-2012
GB 28662-2012	Emission standard of air pollutants for sintering and pelletizing of iron and steel industry	air	27-Jun-2012	1-Oct-2012
GB 28663-2012	Emission standard of air pollutants for iron smelt industry	air	27-Jun-2012	1-Oct-2012
GB 28664-2012	Emission standard of air pollutants for steel smelt industry	air	27-Jun-2012	1-Oct-2012
GB 28666-2012	Emission standard of pollutants for ferroalloy smelt industry	water, air	27-Jun-2012	1-Oct-2012
GB 28936-2012	Discharge standards of water pollutants for reeling industry	water	19-Oct-2012	1-Jan-2013
GB 28937-2012	Discharge standards of water pollutants for woolen textile industry	water	19-Oct-2012	1-Jan-2013
GB 28938-2012	Discharge standards of water pollutants for bast and leaf fibres textile industry	water	19-Oct-2012	1-Jan-2013
GB 4287-2012	Discharge standards of water pollutants for dyeing and finishing of textile industry	water	19-Oct-2012	1-Jan-2013
GB 13458-2001	Discharge standard of water pollutants for ammonia industry	water	14-Mar-2013	1-Jul-2013
GB 19430-2013	Effluent standards of water pollutants for citric acid industry	water	14-Mar-2013	1-Jul-2013
GB 28665-2012	Emission standard of air pollutants for steel rolling industry	air	14-Mar-2013	1-Jul-2013
GB 29495-2013	Emission standard of air pollutants for electronic glass industry	air	14-Mar-2013	1-Jul-2013

Appendix C.2 - Provincial emission standards

Doc No.	Province	Document Title	Pollutant	Effective Date
DB11/206-2003	Beijing	Emission Controls and Limits for Gasoline Vapor on Bulk Gasoline Terminals	air	2003.10.01
DB11/207-2003	Beijing	Emission Controls and Limits for Gasoline Vapor on Tank Truck	air	2003.10.01
DB11/208-2003	Beijing	Emission Controls and Limits for Gasoline Vapor on Gasoline Filling Station	air	2003.10.01
DB11/307-2005	Beijing	Discharge Standard of Water Pollutants	water	2005.09.01
DB11/447-2007	Beijing	Emission Standards of Air Pollutants for Petroleum Refining and Petrochemicals Manufacturing Industry	air	2007.07.01
DB11/139-2007	Beijing	Emission Standard of Air Pollutants for Boilers	air	2007.09.01
DB11/501-2007	Beijing	Integrated Emission Standards of Air Pollutants	air	2008.01.01
DB11/502-2007	Beijing	Emission Standard of Air Pollutants for Municipal Solid Wastes Incineration	air	2008.01.01
DB11/503-2007	Beijing	Emission Standard of Air Pollutants for Hazardous Wastes Incineration	air	2008.01.01
DB11/206-2010	Beijing	Emission Controls and Limits for Gasoline Vapor on Bulk Gasoline Terminals	air	2010.07.01
DB11/207-2010	Beijing	Emission Controls and Limits for Gasoline Vapor on Tank Truck	air	2010.07.01
DB11/208-2010	Beijing	Emission Controls and Limits for Gasoline Vapor on Gasoline Filling Station	air	2010.07.01
DB11/847-2011	Beijing	Emission standard of air pollutants for stationary gas turbine	air	2012.01.01
DB62/1922-2010	Gansu	Emission standard for air pollutants from boilers for Lanzhou City	air	2010.06.10
DB44/26-2001	Guangdong	Discharge Limits of Water Pollutants	water	2002.02.01
DB44/27-2001	Guangdong	Emission Limits of Air Pollutants	air	2002.02.01
DB44/612-2009	Guangdong	Emission standard of air pollutants for thermal power plants	air	2009.08.01
DB44/613-2009	Guangdong	Discharge standard of pollutants for livestock and poultry breeding	water, air	2009.08.02
DB44/765-2010	Guangdong	Emission Standard of Air Pollutants for Boilers	air	2010.11.01
DB44/814-2010	Guangdong	Emission standard of volatile organic compounds for furniture manufacturing operations	air	2010.11.02
DB44/815-2010	Guangdong	Emission standard of volatile organic compounds for printing industry	air	2010.11.03
DB44/816-2010	Guangdong	Emission standard of volatile organic compounds for surface coating of automobiles	air	2010.11.04
DB44/817-2010	Guangdong	Emission standard of volatile organic compounds for shoe-making industry	air	2010.11.05
DB44/818-2010	Guangdong	Emission standard of air pollutants for cement industry	air	2010.11.06
DB13/339-1997	Hebei	Dust Environmental Quality Standards (Trial)	air	1998.05.01
DB13/831-2006	Hebei	Chloride emission standards	water	2007.01.01
DB13/1200-2010	Hebei	Emission standard of air granular matter for iron ore mineral processing factory	air	2010.05.04
DB13/1461-2011	Hebei	Steel industrial air pollutants emission standards	air	2011.11.30

Doc No.	Province	Document Title	Pollutant	Effective Date
DB23/1341-2009	Heilongjiang	Furfural industrial water pollutant discharge standards		2009.08.01
DB41/538-2008	Henan	Ammonia industry wastewater discharge standards	water	2009.01.01
DB41/681-2011	Henan	Beer industrial wastewater discharge standards	water	2011.11.01
DB41/684-2011	Henan	Lead smelting industry emission standards	water, air	2013.01.01
DB32/670-2004	Jiangsu	Discharge Standard of Water Pollutants for Dyeing and Finishing	water	2005.01.01
DB32/939-2006	Jiangsu	Discharge Standard of main water pollutants for chemical industry	water	2006.07.26
DB32/1072-2007	Jiangsu	Discharge Standard of Main Water Pollutants for Municipal Wastewater Treatment Plant & Key Industries of Taihu Area	water	2008.01.01
DB21/1627-2008	Liaoning	Integrated Wastewater Discharge Standard	water	2008.08.01
DB37/336-2003	Shandong	Wastewater discharge standards for paper industry	water	2003.05.01
DB37/533-2005	Shandong	Discharge Standard of Water Pollutants for Dyeing and Finishing	water	2005.05.01
DB37/534-2005	Shandong	Emission standards for livestock and poultry industries		2005.05.01
DB37/532-2005	Shandong	Cement industry emission standards of air pollutants	air	2005.07.01
DB37/597-2006	Shandong	Cooking fume emission standards		2006.01.04
DB37/664-2007	Shandong	Thermal power plant air pollutant emission standards	air	2007.05.01
DB37/676-2007	Shandong	Integrated Wastewater Discharge Standard in Shandong Peninsula Basin	water	2007.10.01
DB37/990-2008	Shandong	Iron and steel industry emission standards	water, air	2008.02.01
DB37/1919-2011	Shandong	Aluminum industry emission standards	air	2011.10.01
DB37/2376-2013	Shandong	Integrated Emission Standards of Air Pollutants	air	2013.09.01
DB37/595-2006	Shandong	Starch processing industrial water pollutant discharge standards	water	2006.01.04
DB31/373-2006	Shanghai	Discharge Standard of Pollutants for Bio-pharmaceutical Industry	water, air	2006.02.01
DB31/374-2006	Shanghai	Discharge Standards of Pollutants for Semiconductor Industry	water, air	2007.02.01
DB31/387-2007	Shanghai	Emission standard for air pollutants from boilers	air	2007.09.01
DB31/445-2009	Shanghai	Discharge Standard for Municipal Sewerage System	water	2009.09.01
DB31/199-2009	Shanghai	Integrated wastewater discharge standard	water	2009.10.01
DB31/373-2010	Shanghai	Discharge Standard of Pollutants for Bio-pharmaceutical Industry	water, air	2010.07.01
DB31/387-2013	Shanghai	Emission standard for air pollutants from boilers	air	2007.09.01
DB12/151-2003	Tianjing	Tianjin Emission Standard of air pollutants of gas-fired boiler	air	2003.10.01
DB12/356-2008	Tianjing	Tianjin Integrated Wastewater Discharge Standard	water	2008.02.18
DHJB1-2001	Zhejiang	Discharge standard of water pollutants for Paper Industry (Waste Paper Material)	water	2001.03.01
DB33/844-2011	Zhejiang	Concentration Limits of total iron for acid-washing wastewater	water	2012.04.01

Appendix D - Firm Total Factor Productivity by Industry

Table 14: Summary Statistics: Log of Total Factor Productivity

Industry	Observations	Mean	Std. Dev.	Min	Max
06 Mining and washing of coal	40,758	1.4451	1.1081	-6.7929	8.2115
07 Extraction of petroleum and natural gas	1,188	2.0629	1.1789	-2.7169	8.8395
08 Mining and processing of ferrous metal ores	12,654	2.0516	1.0459	-5.3963	6.3698
09 Mining and processing of non-ferrous metal ores	14,148	1.7890	1.1993	-6.8271	6.9376
10 Mining and processing of nonmetal ores	19,896	1.6316	1.1132	-4.8978	6.4699
11 Mining of other ores	167	1.7465	1.2073	-1.1337	5.8985
13 Agricultural and sideline foods processing	119,817	1.9215	1.2752	-8.0305	8.4119
14 Food production	47,832	1.4890	1.2342	-8.6554	7.1202
15 Beverage production	33,143	1.5854	1.1921	-7.5451	6.2231
16 Tobacco products processing	2,423	1.9425	1.1624	-4.0327	5.3240
17 Textile industry	168,851	1.5422	0.9518	-8.4353	8.7363
18 Clothes, shoes, and hat manufacture	94,397	1.4937	0.8748	-8.0259	6.2890
19 Leather, furs, down, and related products	46,805	1.6529	0.9726	-7.6967	6.6918
20 Timber processing, bamboo, cane, palm fiber, and straw products	39,521	1.7350	1.0014	-6.6676	6.6768
21 Furniture mfg.	22,654	1.5765	0.9965	-7.5875	6.2572
22 Papermaking and paper products	58,314	1.5713	0.9523	-7.9712	6.9524
23 Printing and record medium reproduction	41,217	1.0948	1.0289	-8.5460	6.1020
24 Cultural, educational, and sports articles prod.	25,609	1.4485	0.8979	-7.0378	5.7727
25 Petroleum processing, coking, and nuclear fuel processing	14,038	2.1028	1.1269	-4.3574	7.3754
26 Raw chemical material and chemical products	144,706	1.7780	1.0817	-8.1778	8.1254
27 Medical and pharmaceutical products	40,713	1.6658	1.0685	-7.6346	7.9412
28 Chemical fiber	9,800	1.6877	1.0184	-7.0230	6.5383
29 Rubber products	23,179	1.5502	0.9764	-6.7494	6.5981
30 Plastic products	90,657	1.5796	0.9659	-7.1312	7.7374
31 Nonmetal mineral products	167,783	1.4601	1.0132	-8.7741	8.2992
32 Smelting and pressing of ferrous metals	46,473	1.9752	1.1214	-10.556	7.6070
33 Smelting and pressing of nonferrous metals	37,371	2.0904	1.2189	-7.5376	7.8300
34 Metal products	105,379	1.6206	0.9894	-7.0520	7.9453
35 Ordinary machinery mfg.	147,777	1.5451	1.0001	-8.6366	7.1041
36 Special equipment mfg.	81,355	1.4432	1.1392	-7.7331	7.7482
37 Transport equipment mfg.	87,933	1.4721	1.0601	-8.7930	7.2138
39 Electric machines and apparatuses mfg.	115,121	1.6912	1.0219	-7.4842	10.1216
40 Communications equipment, computer and other electronic equipment mfg.	63,481	1.5458	1.1021	-9.4090	9.9221
41 Instruments, meters, cultural and office machinery manufacture	27,457	1.4649	1.1091	-8.3360	7.0386
42 Craftwork and other manufactures	43,721	1.6040	0.9830	-6.0353	7.7613
43 Waste resources and old material recycling and processing	2,017	2.3594	1.2198	-3.4915	6.5903
44 Electricity and heating production and supply	48,303	1.0046	1.0274	-7.7665	12.2289
45 Fuel gas production and supply	3,539	0.9578	1.3501	-7.3840	5.9117
46 Water production and supply	22,999	0.4041	0.7977	-7.2641	7.4707

Appendix E - Pollution intensity by industry

Most water pollutant-intensive industries

COD Emissions (in kilos) per thousand yuan output

Industry	Average 1998-2000	Average 2001-2004	Average 2005-2008	Total Average
Papermaking and paper products	33.111	10.729	4.518	14.574
Agricultural and sideline foods processing	5.774	2.469	1.295	2.943
Water production and supply	3.524	2.823	2.380	2.853
Beverage production	3.558	1.823	0.880	1.953
Leather, furs, down, and related products	3.355	1.083	0.721	1.571
Food production	2.927	1.437	0.563	1.526
Chemical fiber	2.124	0.980	0.594	1.152
Mining and Processing of Nonmetal Ores	1.743	1.039	0.708	1.111
Medical and pharmaceutical products	1.739	0.986	0.481	1.008
Mining and Processing of Non-ferrous Metal Ores	1.325	0.678	0.903	0.936
Fuel gas production and supply	0.845	0.544	1.326	0.911
Raw chemical material and chemical products	1.432	0.815	0.452	0.851
Textile industry	1.332	0.776	0.536	0.840

Ammonia Nitrogen Emissions (in kilos) per thousand yuan output

Industry	Average 1998-2000	Average 2001-2004	Average 2005-2008	Total Average
Fuel gas production and supply	.	0.168	0.387	0.278
Raw chemical material and chemical products	.	0.323	0.145	0.234
Water production and supply	.	0.165	0.209	0.187
Papermaking and paper products	.	0.192	0.103	0.147
Food production	.	0.176	0.069	0.122
Agricultural and sideline foods processing	.	0.120	0.069	0.095
Leather, furs, down, and related products	.	0.093	0.085	0.089
Mining and Processing of Nonmetal Ores	.	0.047	0.034	0.040
Petroleum processing, coking, and nuclear fuel processing	.	0.053	0.026	0.039
Beverage production	.	0.046	0.032	0.039
Medical and pharmaceutical products	.	0.037	0.031	0.034
Textile industry	.	0.033	0.028	0.030
Smelting and pressing of nonferrous metals	.	0.040	0.015	0.028

Petroleum Emissions (in kilos) per thousand yuan output

Industry	Average 1998-2000	Average 2001-2004	Average 2005-2008	Total Average
Water production and supply	0.067	0.031	0.012	0.034
Extraction of Petroleum and Natural Gas	0.037	0.016	0.007	0.019
Fuel gas production and supply	0.028	0.013	0.003	0.013
Smelting and pressing of ferrous metals	0.028	0.011	0.003	0.012
Petroleum processing, coking, and nuclear fuel processing	0.018	0.009	0.006	0.010
Raw chemical material and chemical products	0.022	0.009	0.003	0.010
Mining and Processing of Non-ferrous Metal Ores	0.013	0.005	0.001	0.006
Medical and pharmaceutical products	0.012	0.003	0.001	0.005
Ordinary machinery manufacturing	0.011	0.003	0.001	0.004
Chemical fiber	0.008	0.003	0.001	0.004
Food production	0.003	0.001	0.005	0.003
Papermaking and paper products	0.007	0.002	0.001	0.003
Special equipment manufacturing	0.006	0.002	0.001	0.003

Industry water and air pollution intensity
(kilogram /000 RMB output)

Industry	COD equivalent water pollution			SO2 equivalent air pollution		
	Average 1998-00	Average 2001-04	Average 2005-08	Average 1998-00	Average 2001-04	Average 2005-08
06 Mining and washing of coal	0.852	0.490	0.283	3.422	1.870	1.253
07 Extraction of petroleum and natural gas	0.518	0.295	0.155	0.330	0.187	0.242
08 Mining and processing of ferrous metal ores	1.062	0.568	0.301	7.185	3.483	1.676
09 Mining and processing of non-ferrous metal ores	2.292	1.013	1.168	3.472	1.387	2.715
10 Mining and processing of nonmetal ores	1.844	1.141	0.783	13.270	6.673	7.268
11 Mining of other ores	0.361	0.406	0.484	2.670	2.283	2.430
13 Agricultural and sideline foods processing	5.821	2.634	1.387	1.439	1.074	0.671
14 Food production	2.959	1.665	0.703	1.183	0.894	0.761
15 Beverage production	3.599	2.077	0.957	1.644	1.407	0.831
16 Tobacco products processing	0.099	0.045	0.016	0.144	0.104	0.081
17 Textile industry	1.355	0.827	0.568	1.202	0.951	0.783
18 Clothes, shoes, and hat manufacture	0.567	0.237	0.286	0.532	0.345	0.374
19 Leather, furs, down, and related products	3.395	1.221	0.838	0.321	0.345	0.318
20 Timber processing, bamboo, cane, palm fiber, and straw products	.	0.946	0.440	.	2.245	1.624
21 Furniture mfg.	.	0.685	0.174	.	0.670	0.404
22 Papermaking and paper products	33.456	11.026	4.448	4.950	3.275	2.224
23 Printing and record medium reproduction	0.224	0.107	0.112	0.395	0.163	0.125
24 Cultural, educational, and sports articles production	.	0.086	0.066	.	0.456	0.120
25 Petroleum processing, coking, and nuclear fuel processing	0.778	0.395	0.307	1.956	2.090	2.369
26 Raw chemical material and chemical products	1.775	1.340	0.676	2.837	1.897	1.663
27 Medical and pharmaceutical products	1.865	1.073	0.535	0.957	0.546	0.507
28 Chemical fiber	2.207	1.045	0.637	2.560	1.260	1.152
29 Rubber products	0.233	0.117	0.060	1.351	0.608	0.507
30 Plastic products	0.156	0.089	0.099	0.562	0.312	0.402
31 Nonmetal mineral products	0.214	0.184	0.103	27.389	10.998	7.974
32 Smelting and pressing of ferrous metals	0.871	0.399	0.146	3.570	2.192	1.883
33 Smelting and pressing of nonferrous metals	0.685	0.417	0.137	6.407	3.937	1.874
34 Metal products	0.167	0.136	0.077	1.183	0.351	0.206
35 Ordinary machinery mfg.	0.239	0.113	0.044	0.685	0.288	0.155
36 Special equipment mfg.	0.188	0.152	0.049	0.500	0.287	0.141
37 Transport equipment mfg.	0.172	0.081	0.034	0.315	0.138	0.071
39 Electric machines and apparatuses mfg.	0.080	0.061	0.039	0.227	0.131	0.087
40 Communications equipment, computer and other electronic equipment mfg.	0.085	0.053	0.038	0.130	0.062	0.041
41 Instruments, meters, cultural and office machinery manufacture	0.299	0.078	0.024	0.510	0.100	0.037
42 Craftwork and other manufactures	0.178	0.137	0.101	0.594	0.367	0.172
43 Waste resources and old material recycling and processing	.	0.097	0.120	.	0.187	0.191
44 Electricity and heating production and supply	0.480	0.325	0.139	34.901	26.298	25.008
45 Fuel gas production and supply	1.614	1.014	2.599	4.067	3.363	4.116
46 Water production and supply	4.236	3.352	2.777	0.937	0.803	0.493

Most air pollutant-intensive industries

SO₂ Emissions (in kilos) per thousand yuan output

Industry	Average 1998-2000	Average 2001-2004	Average 2005-2008	Total Average
Electricity and heating production and supply	27.589	22.760	18.026	22.356
Nonmetal mineral products	10.276	4.868	3.081	5.693
Mining and Processing of Nonmetal Ores	5.557	4.323	3.512	4.365
Smelting and pressing of nonferrous metals	5.285	3.109	1.221	3.016
Mining and Processing of Ferrous Metal Ores	5.479	2.306	0.683	2.581
Fuel gas production and supply	3.601	2.378	1.827	2.511
Papermaking and paper products	3.449	2.413	1.324	2.300
Smelting and pressing of ferrous metals	2.288	1.401	0.920	1.468
Raw chemical material and chemical products	2.134	1.410	0.948	1.439
Petroleum processing, coking, and nuclear fuel processing	1.368	1.486	1.285	1.381
Mining and Washing of Coal	2.118	1.242	0.504	1.213
Chemical fiber	2.019	1.019	0.681	1.169
Mining and Processing of Non-ferrous Metal Ores	1.152	1.089	1.104	1.112

Soot Emissions (in kilos) per thousand yuan output

Industry	Average 1998-2000	Average 2001-2004	Average 2005-2008	Total Average
Electricity and heating production and supply	12.994	9.219	7.678	9.688
Nonmetal mineral products	11.550	3.927	2.417	5.457
Mining and Processing of Nonmetal Ores	6.066	2.598	3.290	3.795
Mining and Processing of Ferrous Metal Ores	5.779	1.363	0.380	2.210
Mining and Washing of Coal	3.880	1.051	0.329	1.560
Papermaking and paper products	2.533	1.523	0.794	1.533
Fuel gas production and supply	1.643	1.182	1.231	1.325
Timber processing, bamboo, cane, palm fiber, and straw products	.	1.604	0.823	1.213
Petroleum processing, coking, and nuclear fuel processing	0.960	0.945	0.931	0.944
Mining of Other Ores	0.616	1.032	1.099	0.943
Smelting and pressing of nonferrous metals	1.347	1.001	0.535	0.926
Raw chemical material and chemical products	1.133	0.777	0.555	0.793
Beverage production	1.208	0.886	0.384	0.791

Dust Emissions (in kilos) per thousand yuan output

Industry	Average 1998-2000	Average 2001-2004	Average 2005-2008	Total Average
Nonmetal mineral products	45.096	16.288	8.923	21.467
Mining and Processing of Nonmetal Ores	3.996	5.407	4.340	4.634
Fuel gas production and supply	3.387	2.179	0.230	1.800
Mining and Processing of Ferrous Metal Ores	3.436	1.687	0.591	1.766
Smelting and pressing of ferrous metals	2.861	1.520	0.766	1.611
Mining of Other Ores	0.005	2.663	0.849	1.279
Smelting and pressing of nonferrous metals	0.907	0.823	0.282	0.649
Mining and Washing of Coal	0.732	0.629	0.540	0.625
Petroleum processing, coking, and nuclear fuel processing	0.579	0.369	0.423	0.446
Clothes, shoes, and hat manufacture	1.367	0.008	0.070	0.401
Timber processing, bamboo, cane, palm fiber, and straw products	.	0.520	0.269	0.395
Papermaking and paper products	1.105	0.145	0.035	0.367
Mining and Processing of Non-ferrous Metal Ores	0.287	0.399	0.249	0.314

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