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Environmental Regulations and Competitiveness: Evidence based on Chinese firm data*

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(Preliminary Draft)

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 water 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 three years.

Keywords: Environmental regulations, Innovation, Productivity, Porter hypothesis, China
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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, suggesting 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 background[1]

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

[1]Summary 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

[2] China 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), SO_2, NO_2, 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 PM2.5. 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 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.[3]

$$k_{it} = \int_0^t l_{i\tau} \mathrm{d}\tau \tag{1}$$

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

$$c_{it} = f\big(l_{it}, w_{it}, k_{it}\big) \tag{2}$$

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

$$u = \int_t^{\infty} \beta^{(\tau - t)} \big(c_\tau - \gamma W_\tau\big) d\tau \tag{3}$$

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:

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

$$\frac{df}{dw} = N\gamma \tag{4}$$

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.

3.1 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:

$$f\big(l, w, k\big) < g\big(l, w, k\big) \text{ for any given } l, w, k \tag{5}$$

Equation (5) 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 $b\big(l, w, k\big)$ that equals the unit waste the producer could abate without sacrificing output. In other words, the waste abatement b satisfies

$$f\big(l, w_f, k\big) = g\big(l, w_f - b, k\big) \text{ for any given } l, w, k \tag{6}$$

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

$$\text{if } \left(t - t_s\right) < \alpha \text{ , then } f\left(l, w, k\right) > g\left(l, w, k\right) \text{ for any given } l, w \tag{7}$$

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

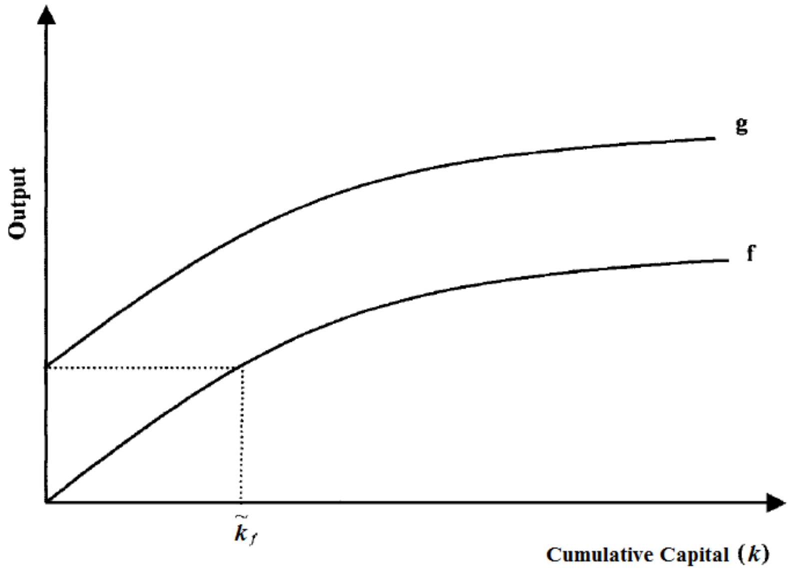


Figure 1 depicts the two technologies and the short-term switching cost. It represents output as a function of cumulative capital k for technologies f and g, with identical levels of l and w. Consistent with equation (5), the curve depicting output for technology g is everywhere above the curve for output 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 (7). The productivity increases again when the producer gradually accumulates capital k_g dedicated to the new technology.

Equations (5) and (7) 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.

3.2 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:

$$\int_t^\infty \beta^{(\tau-t)}\Big(g\big(l_g, w_g^*, k_{g\tau}\big) - \gamma W_g^*\Big)d\tau > \int_t^\infty \beta^{(\tau-t)}\Big(f\big(l_f, w_f^*, k_{f\tau}\big) - \gamma W_f^*\Big)d\tau \quad (8)$$

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 (4) for technology g, and w_f^* is the level of waste that satisfies equation (4) for technology f.

Alternatively, suppose that the government mandates that producers must reduce waste by some amount ε, where $0 < \varepsilon < b\big(l, w_f, k\big)$. 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:

$$\max \int_t^\infty \beta^{(\tau-t)}\Big(g\big(l_{g\tau}, w_{g\tau}, k_{g\tau}\big) - \gamma W_{g\tau}\Big)d\tau \quad \text{subject to } w_{g\tau} \leq \big(\bar{w}_f - \varepsilon\big) \text{ for all } \tau \quad (9)$$

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 $0 < \varepsilon < b\big(l, w_f, k\big)$.

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.

$$g\big(l_g, w_g^*, k_{g\tau}\big) - rw_g^* > f\big(l_f, w_f^*, k_{f\tau}\big) - rw_f^* \tag{10}$$

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.

4 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.

4.1 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 1 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 1: Types of Chinese industrial enterprises by ownership

Year	Total number of Firms	State -owned	Collectively -owned	Private	Foreign -invested	HK, Macao, 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.

4.2 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, Ackerberg 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:

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

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, and m_{it} is the intermediate input also assumed to be non-dynamic. 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:

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

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 2 reports the estimated share of the production inputs - capital stock, labor and intermediate input - 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 therefore captures the value that 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. Both log labor l_{it} and intermediate input m_{it} are used as free variables in the sense that a firm's choice of l_{it} and m_{it} has no impact on the future profits of the firm.

Table 2: Olley-Pakes productivity estimator

	Coefficient	Standard error
lnCapital	0.152248	0.0023732
lnLabor	0.2251768	0.0012411
lnInput	0.6280465	0.0015613
Number of firm-year observations	1314897	
Number of firms	550830	

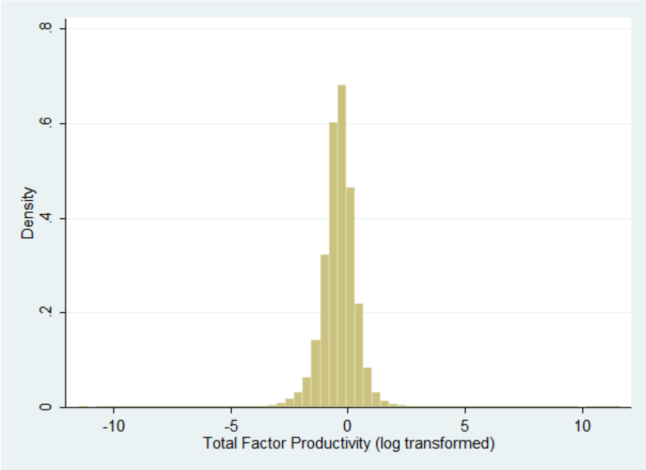
Productivity estimation using the Olley and Pakes method
Dependent variable: log real value-added
State variable: log capital stock k_{it}
Proxy: log investment i_{it}
Free variables: log labor l_{it} and log intermediate input m_{it}

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,[4] and intermediate input m_{it} is calculated as the log value of raw material inputs used in production. All variables are normalized using the input and output price deflators provided in Brandt et al. (2014).

After estimating the share of capital, labor and intermediate input in the firm production function, I calculate the total factor productivity as the residual of the firm value added. Figure 2 shows the density distribution of the natural logarithm of the calculated TFP. The 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).

[4]It 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



4.3 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.[5]

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 SO_2 emission in the corresponding province. SO_2 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

[5]For 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.

the SO_2 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 3 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 3: Effective water and air pollution levy rate
(RMB / kilogram of pollution emission)

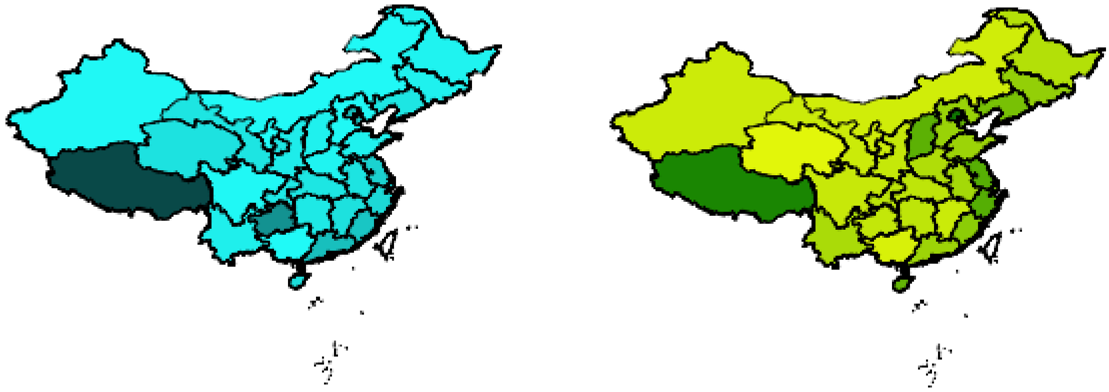
	Effective Water Levy Rate					Effective Air Levy Rate				
Year	Obs	Mean	Std. Dev.	Min	Max	Obs	Mean	Std. Dev.	Min	Max
1998	30	0.3143	0.2016	0.0636	0.8725	30	0.0839	0.0524	0.0156	0.2228
1999	30	0.3619	0.2506	0.0632	1.2030	30	0.1198	0.0777	0.0134	0.3658
2000	30	0.4045	0.3025	0.0148	1.5067	30	0.1037	0.0619	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 SO_2 emissions. The effective levy rates increase over time and varies across provinces.

4.4 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* 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*

Figure 3: Average effective pollution levy rate by province



(a) Effective Water Levy Rate (b) Effective Air Levy Rate

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.

4.5 Industry pollution intensity

Environmental regulations, even when applied across all industries, disproportionally 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 (SO_2), 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 SO_2 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.[6]

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.[7] 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.[8]

Appendix D lists the industrial pollution intensity by measure of COD and SO_2 equivalent pollution emissions. Overall, China's industrial pollution intensity has decreased over the years studied.

[6] The 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.

[7] For 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".

[8] I 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.

5 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.

5.1 Pollution levy

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

$$TFP_{ijpt} = \alpha_0 + \beta_1 PI_{jt} \times L_{pt} + \beta_2 PI_{jt} \times \left(L_{pt}\right)^2 + \beta_3 PI_{jt} \times \left(L_{pt}\right)^3 + \gamma X_{it} + v_{pt} + v_{jt} + v_{jp} + \varepsilon_{ijpt} \quad (11)$$

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 4 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 not statistically significant. However, in column (2) the quadratic term of the effective water pollution levy interacting with pollution intensity displays a statistically significant relationship with productivity at a 95% confidence interval. In column (3), where I also include the cubic term of the effective water pollution levy, the coefficients of the linear, quadratic and cubic terms are all statistically significant. The results display a similar pattern when control variables are included.

A positive coefficient of the quadratic term and negative coefficients of the linear and cubic terms indicate a bell-shaped relationship between the pollution levy and firm productivity. As the levy rate increases, TFP first increases and then goes down beyond a certain point. Based on the estimation results, Appendix A plots the relationship between the pollution levy and TFP. A turning point appears at 3.5 RMB. For a pollution levy rate below that point, an increase in pollution levy is associated with a increase in total factor productivity. When the water pollution levy rate is above 3.5 RMB, total factor productivity decreases with the pollution levy. The unit can be roughly interpreted as pollution levy per thousand RMB output, since the explanatory variable is measured by effective pollution levy (RMB per kg pollution emission) times industry pollution intensity (kg pollution per thousand

Table 4: Water and Air Levy Rate on TFP

	(1) TFP	(2) TFP	(3) TFP	(4) TFP	(5) TFP	(6) TFP
COD Equivalent Pollution Intensity						
× Water Levy	0.0013	-0.0014	-0.0064**	0.0018	-0.0002	-0.0045*
	(0.0012)	(0.0017)	(0.0027)	(0.0012)	(0.0017)	(0.0026)
× Water Levy^2		0.0020**	0.0085***		0.0015	0.0070**
		(0.0009)	(0.0029)		(0.0009)	(0.0029)
× Water Levy^3			-0.0014**			-0.0012**
			(0.0006)			(0.0006)
SO^2 Equivalent Pollution Intensity						
× Air Levy	-0.0062***	-0.0141***	-0.0208***	-0.0069***	-0.0135***	-0.0181***
	(0.0012)	(0.0026)	(0.0037)	(0.0012)	(0.0025)	(0.0037)
× Air Levy^2		0.0066***	0.0206***		0.0055***	0.0151**
		(0.0019)	(0.0063)		(0.0019)	(0.0062)
× Air Levy^3			-0.0075**			-0.0051
			(0.0033)			(0.0033)
S.O.E.				-0.1653***	-0.1653***	-0.1653***
				(0.0023)	(0.0023)	(0.0023)
Foreign				0.0002	0.0002	0.0002
				(0.0023)	(0.0023)	(0.0023)
Hong Kong, Macao, Taiwan				-0.0619***	-0.0619***	-0.0619***
-invested				(0.0022)	(0.0022)	(0.0022)
Private				0.0204***	0.0204***	0.0204***
				(0.0012)	(0.0012)	(0.0012)
Size				0.0629***	0.0629***	0.0629***
				(0.0027)	(0.0027)	(0.0027)
Exporter				-0.0739***	-0.0739***	-0.0739***
				(0.0014)	(0.0014)	(0.0014)
Capital-labor ratio				-0.0000**	-0.0000**	-0.0000**
				(0.0000)	(0.0000)	(0.0000)
Age				-0.0060***	-0.0060***	-0.0060***
				(0.0001)	(0.0001)	(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	2092038	2092038	2092038	2091663	2091663	2091663
R^2	0.1071	0.1071	0.1071	0.1236	0.1236	0.1236
F	14.7618	11.7539	9.6628	3140.8290	2618.2590	2244.6553

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

RMB output).

The effect of the air pollution levy on total factor productivity suggest a more clear negative correlation. The linear term of the levy interacting with air pollution intensity is negatively correlated with productivity, suggesting that a negative relationship exists between the air pollution levy and firm productivity. On average, a one-unit increase in the effective pollution levy is associated with a drop of 0.6% 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. I plot the cubic and quadratic relationship of the air pollution levy and productivity in Appendix A.

In general, I find a bell-shaped relationship between water pollution levy and productivity, while air pollution levy displays a more clear negative correlation with productivity. At first glance, it may seem paradoxical that higher productivity can be associated with a higher pollution levy. 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, resulting in lower productivity. However, when the pollution levy rate is above a certain level, firms may find it more profitable to switch to new, cleaner technologies, resulting in both reductions in pollution and increases in productivity.

5.2 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:

$$TFP_{ijpt} = \alpha_{jt} + \sum_{t=1}^{T} \beta_t S_{jpt} + \mu_i + \varepsilon_{ijpt} \tag{12}$$

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 trends that might affect productivity and pollution emission standards, I include in the differenced question two-digit industry dummies that account for unobserved trends at broad sector levels.

$$\Delta TFP_{ijp} = \Delta\alpha_j + \sum_{t=1}^{T} \beta_t \Delta S_{jp} + \Delta\varepsilon_{ijp} \tag{13}$$

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.

$$\Delta TFP_{ijp} = \Delta\alpha_j + \sum_{t=1}^{T} \beta_t \Delta S_{jp} + \gamma_1 GDP_{pt} + \gamma_2 L_{pt} + \Delta\varepsilon_{ijp} \tag{14}$$

Table 5 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. 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 of around -0.02 to -0.04 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 2-4 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 the prediction that a pollution emission standard can lead to an initial decline in productivity but that it eventually induce firms to improve productivity in the long run.

Table 5: Water and Air Pollution Standards on TFP

	(1)	(2)	(3)	(4)	(5)	(6)
	ΔTFP	ΔTFP	ΔTFP	ΔTFP	ΔTFP	ΔTFP
Standard $_{year1}$	-0.0248*	-0.0418**	-0.0269*	-0.0443**	-0.0277**	-0.0449**
	(0.0142)	(0.0181)	(0.0139)	(0.0178)	(0.0134)	(0.0176)
Standard $_{year2}$	-0.0238**	-0.0379	-0.0267**	-0.0411	-0.0274***	-0.0413*
	(0.0111)	(0.0269)	(0.0104)	(0.0261)	(0.0092)	(0.0250)
Standard $_{year3}$	-0.0070	-0.0105	-0.0097	-0.0145	-0.0100	-0.0153
	(0.0144)	(0.0336)	(0.0146)	(0.0334)	(0.0150)	(0.0327)
Standard $_{year4}$	0.0093	0.0109	0.0075	0.0073	0.0074	0.0062
	(0.0110)	(0.0316)	(0.0111)	(0.0317)	(0.0115)	(0.0312)
Standard $_{year5}$		0.0103		0.0080		0.0063
		(0.0303)		(0.0302)		(0.0297)
Standard $_{year6}$		0.0318		0.0330		0.0307
		(0.0319)		(0.0319)		(0.0314)
GDP per capita			-0.0006***	-0.0006***	-0.0002	-0.0001
			(0.0001)	(0.0001)	(0.0001)	(0.0002)
Water Levy					0.0010	0.0064**
					(0.0022)	(0.0031)
Air Levy					-0.0256***	-0.0480***
					(0.0047)	(0.0064)
constant		0.0099***	0.0250***	0.0248***	0.0274***	0.0328***
		(0.0013)	(0.0020)	(0.0031)	(0.0023)	(0.0037)
Observations	543746	165036	543746	165036	543602	165036
R^2	0.0004	0.0005	0.0005	0.0008	0.0006	0.0012
F	4.6561	13.2892	11.6281	22.3138	12.0312	43.9312

Dependent variable to first difference of total factor productivity of a firm. Standard errors are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

5.3 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. 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. Firm productivity might therefore be a reason, rather than a result, of the pollution levy it is subject to. However, the reverse causality is less of a concern in the current study, as the pollution levy rate is calculated at the provincial-level while total factor productivity is calculated at the firm-level. 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.

6 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

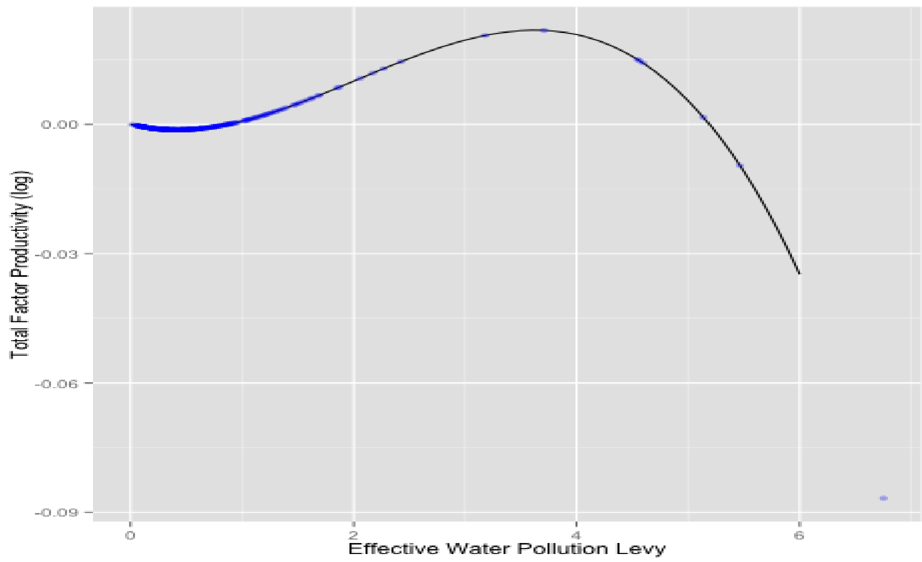
3.5 RMB for roughly per thousand RMB output, and decreases when the pollution levy rate exceeds 3.5 RMB. For the air pollution levy, one can observe a negative correlation between the levy rate and productivity. On average, a one-unit increase in the pollution levy is associated with a drop of 0.6% in 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.

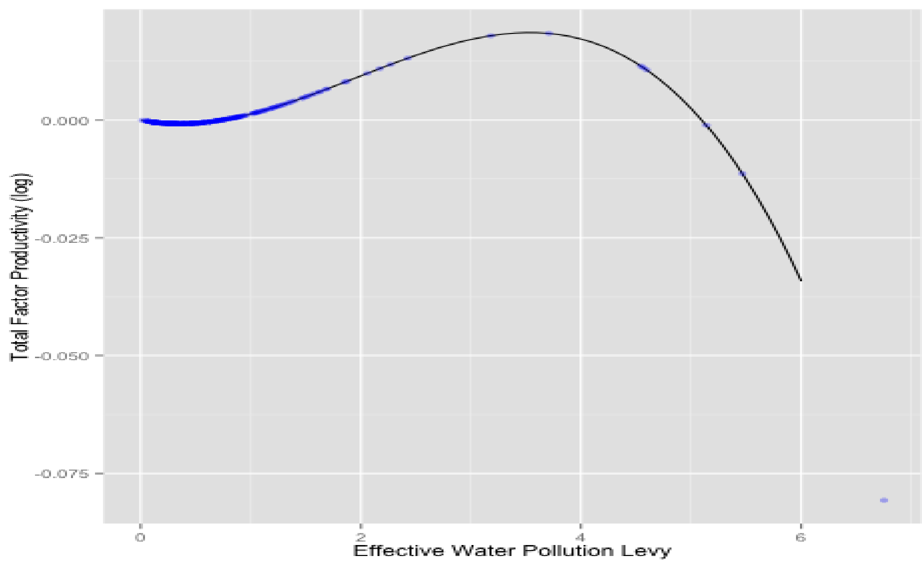
The empirical study in this paper focuses on the correlation, not causality, between pollution control policies and productivity. However, as provincial-level pollution levies and industry-specific pollution emission standards are not likely to be affected by the productivity of individual firms, the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

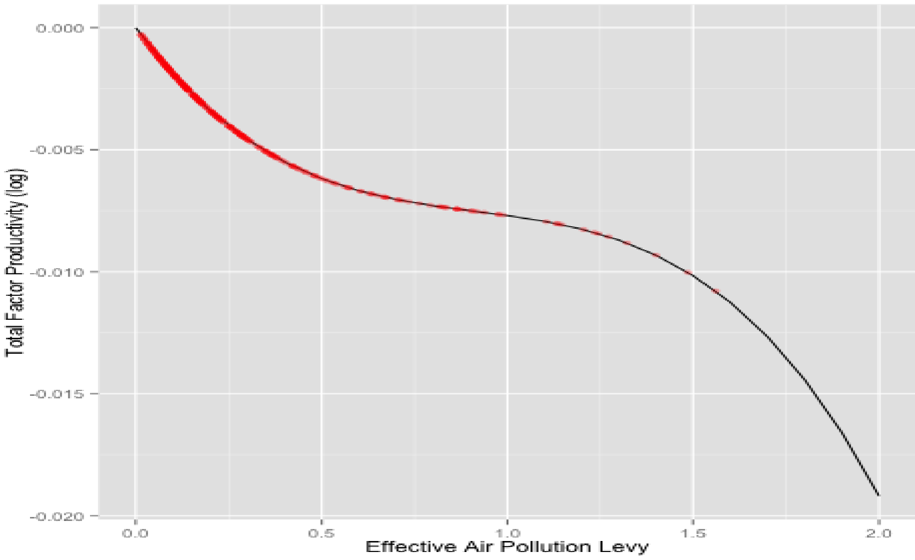
Appendix A - Correlation of pollution levy and TFP



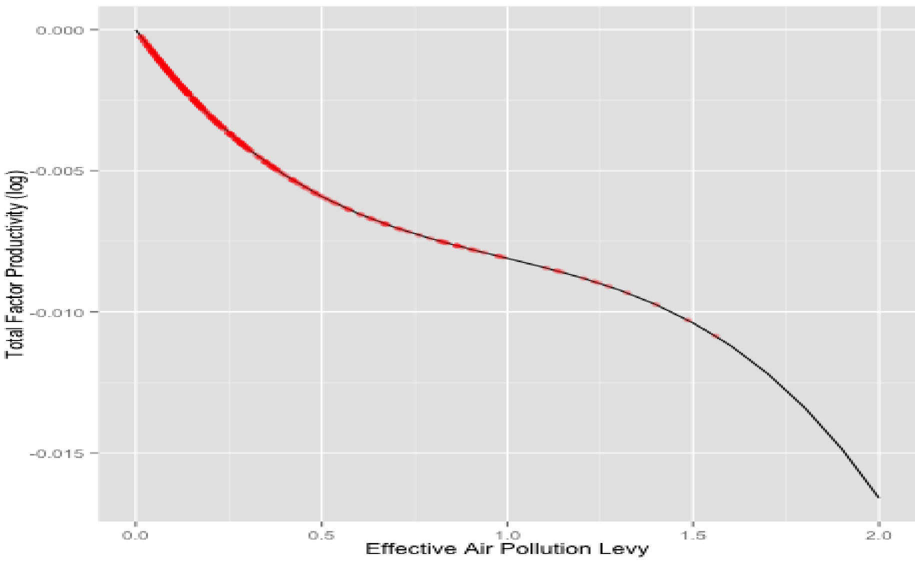
Estimated relationship of water levy and productivity excluding control variables. The blue dots are the actual effective pollution levy rates.



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 SO_2 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 6 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 6: 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:

$$L_i = R_0 W_i \tag{15}$$

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

$$\begin{aligned} P_{ij} &= W_i \frac{C_{ij} - C_{sj}}{C_{sj}} \\ L_{ij} &= \begin{cases} L_{0j} + R_{1j} P_{ij} & \text{if } P_{ij} > T_j \\ R_{2j} P_{ij} & \text{if } P_{ij} < T_j \end{cases} \end{aligned} \tag{16}$$

where for plant i and pollutant j,

P_{ij} = Discharge factor
W_i = Total wastewater discharge
C_{ij} = Pollution concentration
C_{sj} = Concentration standard
L_{ij} = Total levy
L_{0j} = Fixed payment factor
T_j = Regulatory threshold parameter

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 7 lists the national standards on the pollution levy rates R, threshold parameters T and fixed payment L_{0j} for the most common water pollutants[9].

Table 7: 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

$$L_{ij} = Max\Big[0, R_j V_i (C_{ij} - C_{sj})\Big] \tag{17}$$

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.

[9]NEPA, 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 8 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 8: Pollution levy collection in China, 2003-2008
(10 000 RMB)

Year		Total levy	Wastewater	Air pollution	Noise	Hazardous waste
2003		708,975.3				
	Jan-Jun 2003	413,183.0				
	July-Dec 2003	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 SO_2 equivalent for air pollutants. For both water and air pollution, the formula to calculate the equivalent pollution is:

$$E_{ij} = \frac{P_{ij}}{F_j} \tag{18}$$

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 9 lists the conversion parameter F_j for selected water and air pollutants.

Table 9: Pollution conversion parameter for selected pollutants

Pollutant	conversion parameter F_j (kg)
Water pollutants:	
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
Air pollutants:	
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:

$$L_i = R_j * \sum_{j=1}^{3} E_{ij} \tag{19}$$

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 SO_2 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 SO_2 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 10 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 10: 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)	Levy Amount Post-2003 (RMB)
Within-standard polluter:					
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
Above-standard polluter:					
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 - 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

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

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

	Industry	COD equivalent water pollution Average 1998-00	Average 2001-04	Average 2005-08	SO2 equivalent air pollution 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

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