China's provincial industrial pollution: the role of technical efficiency, pollution levy, and pollution quantity control

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Abstract

Using China's provincial economic and pollution data from 1992 to 2008, we employ data envelope analysis (DEA) and econometric analyses to explicitly estimate technical efficiency and examine the role of technical efficiency, pollution control instruments (pollution levy and pollution quantity control), and prices of production inputs on pollution intensity. We find that an increase of labor wage and/or a decrease of capital cost are associated with an improvement in technical efficiency. The levy rates of air pollution improve technical efficiency but pollution quantity control targets have no statistically significant effect on technical efficiency. On the other hand, technical efficiency, the effective levy rates, pollution quantity control targets, and capital cost have a negative effect but wage has a positive effect on pollution intensity. The importance of production input prices in pollution intensity and technical efficiency suggests alternative channels for industrial pollution control as well as cautions for the unintended consequence on the environment if any policy changes are made relating to labor and capital costs.

Key words: pollution control, levy, technical efficiency, total quantity control, China

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1. Introduction

In the last three decades China's economic growth has dwarfed all other economies worldwide with its higher than ten percent annual economic growth rate. China's economic growth has significantly improved living standards, but it also brought serious damage and degradation to its environment. According to a 2007 report released by the Blacksmith Institute, six of the World's 30 most polluted cities were in China (BlackSmithInstitute, 2007).[2] Approximately 43% of China's major cities did not meet its category II air-quality standards in 2006 (SEPA, 2006)[3] and 74% of the Chinese population lived in areas where the air quality did not meet the WHO standards in 2002 (WHO, 2005). Industry, which contributes approximately half of China's GDP, is the primary source of water and air pollution. If left uncontrolled, the environmental damage will be so severe that it will become a bottle-neck for sustainable economic growth.

Recognizing the danger of worsening environmental quality and the increasing demand for better ambient environmental quality, the Chinese government has implemented various policies and invested in technological improvement. As a main pillar of the pollution control system, the levy system was first introduced in the Provisional China Environment Protection Law (EPL) enacted in 1979 and significantly revised in 2003 to provide better incentives for pollution control. In 2006 China implemented quantity control on COD (Chemical Oxygen Demand) and SO_2 (sulfur dioxide) discharge. The target of the quantity control is to reduce major pollutant discharges of COD and SO_2 by ten percent relative to the 2005 levels by the end of the 11th Five-Year Plan Period (2006-2010).

The objective of this study is to explicitly model technical efficiency and investigate the effectiveness of main pollution control instruments, technical efficiency, and prices of production inputs on pollution intensity. Using China's provincial economic and pollution

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[2] Six cities with highly polluted air quality were Wanshan, Tianying, Huaxi, Lanzhou, Linfen, and Urumqi.

[3] The category I and II air quality measures in China are: 100 ug/m^3 and 200 ug/m^3 for TSP; and 30 ug/m^3 and 100 ug/m^3 for PM_{10}.

data from 1992 to 2008, the estimated technical efficiency based on data envelope analysis (DEA) exhibits significant regional differences. Based on the econometric analyses of technical efficiency and pollution intensity, we find that an increase in the pollution levy rates and labor wage or a decrease in capital cost is associated with an improvement in technical efficiency. On the other hand, technical efficiency, effective levy rates, pollution quantity control targets, and capital cost have a negative effect but wage has a positive effect on pollution intensity. The importance of production input prices in technical efficiency and pollution intensity suggests alternative channels for industrial pollution control and calls for cautions regarding the unintended consequences on the environment if any policy changes are made relating to labor and capital costs. Pollution quantity control targets effectively reduce pollution intensity but they do not improve technical efficiency, while the effective levy rates for air pollution are negatively associated with both pollution intensity and technical efficiency. The results suggest that pollution levy, a market-based instrument, may work better than command-based instruments like pollution quantity control as the former gives polluters an incentive to improve technical efficiency that leads to a long-run improvement in pollution control.

2. Background of China’s pollution control system and policy changes

China began to implement environmental regulations as early as the 1970s. A series of pollution control regulations were implemented and enforced at the national, provincial, and local levels following the first Provisional EPL enacted in 1979. The policy spectrum ranges from command-and-control instruments to economic incentives and voluntary pollution control (see details in section 2.3).

2.1. China’s pollution levy system

The pollution levy system has always been a centerpiece of China’s pollution regulations.

Article 18 of the EPL stated that “the levy should be imposed on pollution discharges which exceed national pollution discharge standards, based on quantity and concentration of discharges and levy fee schedules established by the State Council.” By the end of 1981, 27 out of a total of 29 provinces, autonomous regions and municipalities in China started to implement the levy system. In February 1982 China issued an “Interim Procedure on Pollution Charges” (hereafter Procedure). The Procedure defined objectives, levy standards, collection methods, and principles for use of the levy collected. The nationwide implementation of the levy system followed the passage of the Procedure -- discharge of wastewater, waste gas, and solid wastes that are higher than the standards were subject to the levy.

The evolution of the levy system has two distinct periods, pre- and post-2003 regimes. The pre-2003 levy system classifies firms into compliant and noncompliant firms. We denote an individual firm’s concentration of pollutant *i* in category *k* (e.g., wastewater, air pollutants) by C_i^k and the pre-specified standard by $\overline{C}_i^k$. A firm is a compliant firm if the concentration of each pollutant in category *k* does not exceed the pre-specified national standard, that is, $C_i^k \leq \overline{C}_i^k$ for all *i* in *k*; otherwise it is a noncompliant firm if $C_i^k > \overline{C}_i^k$ for at least one pollutant in category *k.*

The levy schedules differ between water and air pollution and across different regimes. In the pre-2003 regime, as shown in the left part of figure 1, the levy on wastewater discharge for a compliant firm is based on the total volume of wastewater discharge (*W*) and the levy rate (R_0^W):

(1) $L_i^w = W R_0^W$.

Insert Figure 1 here!

A uniform levy rate of ¥0.05 per ton of wastewater discharge was used in the pre-2003 regime. Figure 1 also illustrates the block levy rates paid by noncompliant firms in the pre-2003 regime. Formally, the potential levy on pollutant *i* for a noncompliant firm is:

$$(2)\quad L_i^w = \begin{cases} R_{i1}^W p_i^W & \text{if } p_i^W \le T_i^W \\ R_{i1}^W T_i^W + R_{i2}^W (p_i^W - T_i^W) & \text{if } p_i^W > T_i^W \end{cases}$$

where T_i^W is the regulatory threshold separating the discharge higher than the standards from the within-standard discharge; R_{i1}^W and R_{i2}^W are the levy rates for the within discharge and discharge that exceed the standards where $R_{i1}^W > R_{i2}^W$; and p_i^W is a discharge factor that depends on both the total wastewater discharge volume and the degree to which pollutant concentration exceeds the discharge standard, i.e., $p_i^W = \max\left\{0, W\left(C_i^W - \bar{C}_i^W\right)/\bar{C}_i^W\right\}$. The discharge factor varies by pollutants and industry sectors. The central government determines the regulatory threshold and levy rates for each pollutant, T_i^W, R_{i1}^W and R_{i2}^W. All three parameters are invariant within each industry sector and across geographic regions.

The concentration standards vary by pollutants and industry sectors (see table A1 for more details). The pulp paper sector, for example, is subject to looser standards for three main water pollutants, namely, COD, BOD (biochemical oxygen demand) and TSS (total suspended solids), than the textile and beverage sectors. BOD has a lower concentration standard than COD and TSS. The levy rates for COD, SO_2, and TSS are shown to be decreasing block rates – ¥0.18 per ton for within-standard discharge and ¥0.05 for the discharge higher than the standards for both COD and BOD; and the corresponding numbers are ¥0.03 and ¥0.01 for TSS. The amount of levy for water pollution that a noncompliant firm has to pay is the largest levy among all water pollutants:

$$(3)\quad L^w = \max\left\{L_1^w, L_2^w, \cdots, L_n^W\right\}$$

where *n* is the total number of relevant water pollutants discharged by the firm.

In the case of air pollution, only noncompliant firms are subject to pollution levies. For air pollutant *i*, we denote the levy rate by R_i^a, the pollutant concentration by C_i^a, and the corresponding concentration standard by $\bar{C}_i^a$. The potential levy of air pollutant i for a noncompliant firm is

$$(4)\ L_i^a = \max\left\{0, R_i^a\ V\left(C_i^a - \bar{C}_i^a\right)\right\}$$

where V is the total discharge of air pollutant i measured in cubic meters. Unlike the water pollution levy for noncompliant firms (see equation (2)), the air pollution levy is assessed on the absolute, rather than percentage, deviation from the concentration standard. Table A1 provides values of the key parameters for two common air pollutants, SO_2 and TSP (total suspended particles). A special regulation is imposed on SO_2 discharge among noncompliant firms in the acid rain and/or SO_2 control areas (including most coastal areas); however a uniform levy rate, ¥0.2 per kilogram of SO_2 emission, is applicable regardless of the concentration level.

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, air pollution levy being not applicable to compliant firms, and constant rates that are not adjusted for inflation (the real value of the later years was substantially lower than in the early years). The levy system was significantly amended in 2003 and called for two steps to calculate the levy amount in the post-2003 regime. The first step is to convert discharge into either COD equivalent for water pollutants or SO_2 equivalent for air pollutants:

$$(5)\ E_i^K = \begin{cases} W C_i^W / e_i^W & \text{for water pollutants} \\ V C_i^A / e_i^A & \text{for air pollutants} \end{cases}$$

where the regulatory conversion parameters for pollutant i are denoted by e_i^W for water pollution and e_i^A for air pollution. The conversion parameter takes a value of 1 for COD and 0.95 for SO_2. Equation (5) suggests that both compliant and noncompliant firms need to pay for pollution discharge. The pollutants that are more likely to cause environmental damage are assigned with smaller conversion parameter and have greater amount of the equivalents.

The equivalent is calculated for all pollutants in each pollution type k, but only the top three pollutants with the greatest equivalent matter in calculating the levy amount:

$$(6)\quad L_k = R_k \sum_{i=1,2,3} E_i^K$$

where the levy rate R equals ¥0.7 per unit of COD equivalent and ¥0.6 per unit of SO_2 equivalent for the within-standard discharge, but the rates are doubled for the discharge higher than the standards, i.e., ¥1.4 and ¥1.2 for COD and SO_2 equivalent, respectively. In the case of air pollution, all polluting firms, whether they are a compliant or noncompliant firm, need to pay the levy. The rates are the same for firms located in the acid rain and SO_2 control area or other areas.

To illustrate the differences between the pre- and post-2003 levy systems, we assume there are two firms, one compliant firm and one noncompliant firm. As shown in table 1, each emits a total of 500,000 tons of wastewater with three particular pollutants, COD, BOD and TSS. The levy for the compliant firm under the post-2003 levy regime totals up to ¥35,875, increasing from the pre-2003 level of ¥25,000 by 43.5%. For the noncompliant firm, the levy under the post-2003 regime is almost six times the levy under the pre-2003 regime, changing from ¥36,000 to ¥207,625. The numerical comparisons show that the post-2003 levy system penalized all polluters more than the pre-2003 system did and penalized heavy polluters substantially more.

Insert Table 1 here

2.2. Pollution quantity control

China first adopted pollution quantity control to regulate pollution in the environmental special zones[4] during the 9th and 10th Five-Year Plan Periods. The national pollution quantity control imposed on COD and SO_2 was elaborated in the 11th Five-Year Plan Period (2005-2010) released in 2006. The goal was to reduce major pollutant discharges by ten

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[4] The environmental special zones are important to regional eco-system such as Lake Tai on the border of the Jiangsu and Zhejiang provinces and Liao river that is the principal river in Liaoning province.

percent relative to the 2005 levels by the end of the 11th Five-Year Plan Period (2006-2010). In other words, the target was to reduce China's national emission from 14.14 million tons in 2005 to 12.73 million tons in 2010 for COD and from 25.49 to 22.94 million tons for SO_2. The national pollution control target was further decomposed into the provincial and local levels. The greatest reductions required for COD were in Hebei, Jiangsu and Zhejian provinces – more than 15% of their levels in 2005; and for SO_2 were in Beijing, Shanghai, Shandong – more than 20% of their levels in 2005. Hainan, Qinghai, Xinjiang and Xizang (Tibet) provinces were not required to reduce their COD and SO_2 emissions, but were required to maintain their 2005 levels (see Figure A1 for more details). The provincial control targets were then decomposed into the city/county level and finally to individual firms. For instance, a COD quota given to a firm was calculated by its total production in the base year of 2005 multiplied by the standard of wastewater discharged for each unit of production and then multiplied by the corresponding concentration standard of COD, where the standard of wastewater discharged per unit of production was designed to incorporate the local COD control target.

In order to achieve the quantity control targets for COD and SO_2 by the end of 2010, China implemented a number of policies. For example, whether the region had achieved the local target of pollution control became an important criterion to evaluate local officials' performance and promotion. SEPA was elevated to become the Ministry of Environmental Protection (MEP) in March 2008, which strengthened its position in ensuring compliance with environmental regulations. The minister of MEP claimed that "T[t]he total amount control targets have been successfully achieved and the environmental quality of China has been significantly improved over the past 5 years [2005-2010]" as "during the 11th Five-Year Plan Period, China has conducted total amount control of major pollutants. Relative to the 2005 level, COD discharge went down by 12.45% and SO_2 by 14.29%, which exceeded the target level of 10%." However, rigorous research was not found to examine the role of the pollution quantity control.

2.3. Other pollution control instruments

China has implemented different types of pollution control instruments including command-and-control, market incentives instruments, voluntary instruments, and information disclosure (see details in table A2). Below we discuss specific instruments implemented or enforced in recent years.

Like other developing countries, China lacks the technical and administrative capacity for effective monitoring and enforcement of environmental laws, regulations, and standards to employ command-and-control instruments effectively. China has adopted pollution control instruments that provide economic incentives to firms. For example, emission permit trading of COD was first introduced in 2008 in the Tai Lake area, an environmental specific zone (Bi & Liu, 2009).[5] Similar permit trading systems have been adopted in other geographical areas and applied to other pollutants. For instance, Chongqing, Shaanxi and Liaoning provinces established their own COD permit trading market in 2010; and Chongqing and Shaanxi provinces started trading SO_2 emission permits in 2009 and 2010, respectively.

However, market failures and weak institutional supports may limit the effectiveness of market-based instruments. China also used voluntary instruments such as labeling to induce voluntary pollution control. For instance, state environmental friendly firm labeling, ecological friendly labeling, and voluntary reduction of greenhouse gas emissions program[6] were used for voluntary pollution control. On the other hand, corporate performance rating and disclosure (PRD) reduces the information asymmetry between polluters and environmental stakeholders (e.g., consumers, communities, NGOs, investors), empowering

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[5] The pilot program of COD emission permit trading at Tai Lake involves 133 industrial firms and 75 wastewater treatment plants. The initial temporarily price is 4600 yuan per ton per year (see (Bi & Liu, 2009)).

[6] According to China Beijing Environment Exchange (CBEEX), 41 firms voluntarily reduced carbon emissions by 210 thousands tons in 2010 (see http://www.cbeex.com.cn/).

these stakeholders to pressure polluters for improved environmental performance (Bui & Mayer, 2003; Foulon, Lanoie, & Laplante, 2002; Kennedy, Laplante, & Maxwell, 1994; Oberholzer-Gee & Mitsunari, 2006). The literature has documented positive effects of PRD programs on regulatory compliance (Dasgupta, Wang, & Wheeler, 2007; García, Afsah, & Sterner, 2009; García, Sterner, & Afsah, 2007; Wang et al., 2004). In 1999, China launched its first pilot program of PRD called Green Watch program in Zhenjiang City, Jiangsu Province and Hohhot City, Inner Mongolia Autonomous District. The Green Watch Program rates firms' environmental performance from best to worst by five colors and discloses firms' color rating to the public. It improved the compliance rates and decreased pollution discharge and pollution intensity (Jin, Wang, & Wheeler, 2010; Wang et al., 2004). Given the success of its pilot program, the Green Watch program was extended to Jiangsu Province in 2001, to eight other provinces during 2003-2005, and promoted to a nationwide implementation since 2005. The Chinese government adopted two critical disclosure measures to improve environmental transparency effectively on May 1st, 2005, namely, *Government Information Disclosure Regulations* (hereafter Regulations) by China's State Council and provisional *Environmental Information Disclosure Measures* (hereafter Measures) by the MEP. The Regulations state citizens, legal persona, and other organizations have the right to obtain government information by lawful means. The Measures stipulate that: (1) firms listed for violating discharge standards or exceeding discharge quota limits are required to publish their discharge data within 30 days in local media and register the data with the local government agency; (2) noncompliant polluting firms are required to publish their discharge data by relevant local government agencies; (3) the environmental agencies will be legally bound to disclose the list of polluters within 20 days through different channels. If the government agencies fail to fulfill the requirements, the public is entitled to apply for the disclosure and the environmental agencies are required to respond within 15 days. If the agencies turn down the public application for disclosure, the public may report this to the superior environmental authority and/or apply for administrative review or file administrative suits.

To promote corporate social responsibility (CSR) and to foster environmentally and socially sustainable private sector development, the stock markets in China took initiatives. The Shenzen Stock Exchange and the Shanghai Stock Exchange issued voluntary CSR guidance for their listed companies in early 2006 and May 2008, respectively. The MEP and the China Securities Regulatory Commission (CSRC) jointly launched the "Green Securities" policy in February 2008 and then the "Green IPO" policy in June 2008. The "Green Securities" policy aims to make it harder for polluting firms to raise capital by requiring publically traded companied to disclose information about their environmental record. The "Green IPO" policy requires firms who want to apply for an initial IPO to include their environmental performance assessment by the MEP along with financial records for the 36 months in their application before initiating an IPO or receiving refinancing from banks. The MEP conducts assessments and calls for public opinions during a ten-day pre-IPO evaluation period. The applicant firm cannot further pursue an IPO without approval from the MEP. Between February 2008 when the policy was first implemented and September 2008, 20 out of 38 companies were rejected for further review of IPOs because of this procedure (Siddy, 2009). The CSRC and the MEP developed a guide on environmental information disclosure of public listed companies in September 2010, which requires the listed companies to disclose their environmental performance regularly and to report environmental accidents within 24 hours after they occur.

We are not able to estimate the effectiveness of these most recently implemented policies because of the lack of data availability. Our empirical analyses mainly focus on the pollution levy system and the pollution quantity control.

3. A brief literature review of pollution control in China

A rich literature investigates environmental regulations and industrial pollution control in China with a focus on the effectiveness of the levy system. The literature has documented a negative association between the levy rates and pollution discharge and/or pollution intensity based on either firm-level pollution data (Dasgupta, Laplante, Mamingi, & Wang, 2001; Wang & Jin, 2007; Wang, Mamingi, Laplante, & Dasgupta, 2003; Wang & Wheeler, 2005) or provincial data (Jiang & McKibbin, 2002). Jiang and Mckibbin (2002) find that the pollution levy effectively reduces water pollution, air pollution, and solid wastes discharge. The actual levy that a polluting firm pays (hereafter effective levy) may deviate from what it deserves to pay. Consequently, the effective levy rate, which is the actual levy payments divided by the total pollution discharge, may deviate from the official levy rate. The significant disparity in the effective levy rates may be due to differences in ownership structures, economic development, and strictness of environmental enforcement (Jiang & McKibbin, 2002; Wang & Wheeler, 2005). Wang and Wheeler (2005) state two possible channels through which provincial and local environmental authorities can affect the size of the effective levy. First, concentration standards, one critical factor in calculating the levy amount, are jointly set by local and central regulators, which can vary by regions. Second, "the levy can be reduced or even eliminated at the discretion of local regulators after appropriate inspections" (Wang & Wheeler, 2005, p. 181). Wang *et al*. (2003) find that state-owned firms have greater bargaining power with local environmental authorities and, thus, successfully negotiate for a lower effective levy rate, which partly explains these firms' worse environmental performance compared with other firms. Wang and Wheeler (2005) show that relatively affluent, heavily industrialized coastal provinces had the highest effective levy rates for wastewater, while less developed inland provinces had the minimum rates in the pre-2003 regime. The region-variant levy rates play an important role when foreign directed investment firms choose their location (Dean, Lovely, & Wang, 2009; Di, 2007).

Different from the ex-post self-report in western countries, firms in China self-report their pollution discharge ex ante (Wang & Wheeler, 2005). At the beginning of each year, firms have to register with the local environmental authorities by providing the predicted volume of emissions in the coming year. Environmental authorities verify the registration reports and issue pollution discharge licenses to firms. During the year, firms are required to modify their reports as needed – when their actual emissions are different from those predicted at the beginning of the year. Moreover, environmental authorities conduct field inspections. At the end of each quarter, based on firms' reports and inspections, authorities notify firms of the amount of levies they should pay in this quarter. In case of false reporting (either at the original report or at the time plants must modify their estimates) and being caught by the authorities, firms are liable to pay the evaded levy and between 100% and 300% extra for penalties. When a plant badly underreports and is caught, besides the regular penalty, it also faces a fixed amount of additional penalty. The total monetary penalty should not exceed the ceiling of ¥100,000 (around 16,000 USD). Other non-monetary penalty instruments are also available, such as revoking discharge licenses and shutting down facilities, but they are rarely used. The ex-ante self-report and limited penalties for a false report lead to weak enforcement (Lin, 2011; Wang & Wheeler, 2003). For instance, firms can strategically underreport their pollution at the beginning of the year and decide whether to modify their report by observing whether they are inspected or not. To induce a truthful self-report, both expected and unexpected site-inspections are occasionally conducted by local environmental authorities. Dasgupta *et al*. (2001) show that the frequency of such inspections is negatively associated with firms' pollution levy. Lin (2011) provides a theoretical framework to support the effect of inspections in inducing truthful reporting among polluting firms and the empirical results confirm the expectation.

4. The model

The empirical analysis consists of two parts. We first estimate technical efficiency using DEA and then investigate factors affecting technical efficiency and pollution intensity. We employ an R-package for DEA and Stata for regression analyses.

4.1. Estimation of technical efficiency

Technology and environmental management is an important determinant of pollution (Managi & Kaneko, 2009). Using time trend variables to proxy technology changes, which is a common practice in the existing literature, is likely to capture any time-varying effects that are not necessarily related to technology. Thus, it is important to explicitly estimate technical efficiency. There is an ongoing debate whether deterministic methodologies such as DEA or stochastic methodologies such as stochastic frontier analysis should be used (Bravo-Ureta *et al.*, 2007). Using a meta-analysis to review empirical studies investigating agriculture technical efficiency in developing countries, Thiam, Bravo-Ureta, and Rivas (2001) find no statistically significant differences in these estimates between using stochastic and deterministic approaches. Managi and Kaneko (2009) employ DEA to explicitly estimate technical efficiency and then incorporate it as one of the determinants of pollution abatement. We use a similar approach, but our focus is on the effectiveness of technical efficiency on pollution control.

DEA, developed by Charnes (1978), is a nonparametric methodology for evaluating the relative efficiency of a set of comparable entities called decision making units (DMUs) with multiple inputs and outputs. It has gained popularity in environmental performance measure by incorporating undesired output (pollution) along with the desirable output (production) in the traditional DEA framework (Li, 2010; Zaim, 2004; Zhou, Ang, & Poh, 2008a, 2008b; Zhou, Poh, & Ang, 2007). See Zhou *et al.* (2008b) for a detailed review of DEA in energy and environmental studies.

Suppose we observe a sample of *I* DMUs. Each of them use *N* different inputs $X=\left(x_1,x_2,...,x_N\right)\in R_+^N$ to produce *M* different desirable outputs $Y=\left(y_1,y_2,...,y_M\right)\in R_+^M$, and *K* different undesirable outputs (pollution) $Z=\left(z_1,z_2,...,z_K\right)\in R_+^K$. The production technology can be characterized by $T=\left\{(X,Y,Z):X \text{ produce } (Y,Z)\right\}$. Besides satisfying standard regularity conditions like convexity and closeness (see details at Fare and Primont (1995) and Cooper *et al*. (2006)), the technology *T*(*X,Y,Z*) also satisfies the following two properties to account for negative production externalities:

P1: Outputs are weakly disposable, i.e., $\text{if } (X,Y,Z)\in T$ *and* $0\leq\theta\leq 1$ *, then* $(X,\theta Y,\theta Z)\in T$.

P2: Desirable and undesirable outputs are null-joint, i.e., $\text{if } (X,Y,Z)\in T$ *and Z=0, then Y=0.*

P1 suggests that the proportional reduction in desirable and undesirable outputs is feasible. For example, to reduce pollution (undesirable output), a proportionate reduction in desirable output is needed. P2 implies that the production with only desirable outputs is impossible, and the only way to eliminate all undesirable outputs is to stop production.

Technical efficiency is the ability of a decision-maker to maximize output with given quantities of inputs and certain technology (output-oriented), or the ability to minimize input uses with a given output target (input-oriented). Output-oriented technical efficiency is commonly used. In particular, following Tyteca (1997) the technology efficiency for DMU *i* at time *t* is defined as

$$(7)\quad TE^{it}\left(X^{it},Y^{it},Z^{it}\right)=\max\left\{\phi:\left(X^{it},Y^{it},Z^{it}/\phi\right)\in T^{it}\right\}.$$

We define two types of outputs: the undesired environmental output that is denoted by *Z* and measured by COD- and SO_2-equivalent emissions, and the desired output that is denoted by *Y* and measured by provincial gross industry productivity. The production inputs denoted by *X* consist of labor and capital. Equation (7) suggests an improvement in technology efficiency shifts the production possibility frontier (PPF) outwards since more can be produced from the same amount of inputs given the improvement. Following equation (7), the technical efficiency score (*TES*) of province i at time t is

$$(8)\ TES^{i,t} = \frac{TE^{i,t}(X^{i,t}, Y^{i,t}, Z^{i,t})}{\max\limits_{i,t} TE^{i,t}(X^{i,t}, Y^{i,t}, Z^{i,t})}$$

A greater *TES* implies higher technical efficiency.

We then investigate provincial variations of technical efficiency by employing econometric models. We assume that technical efficiency in province i at time t denoted by TE_{it} is a function of input prices ($PXit$) consisting of labor wage and capital cost, pollution control variables (levy rates and quantity control targets) represented by Q_{it}, province-specific economic factors (M_{it}), region-specific time trends (γ_i), and province effects (θ_i). The reduced structural equation for technical efficiency is

$$(9)\ TE_{it} = \theta_i + \gamma_i t + \beta_1 PX_{it} + \beta_2 Q_{it} + \beta_3 M_{it} + \varepsilon_{it}.$$

We expect β_1 to be positive as a higher input price is expected to provide an incentive for being more technically efficient. We also expect β_2 to be positive as a higher levy rate or a larger quantity control target also gives firms an incentive to improve technical efficiency so that the undesirable output (pollution) can be reduced. The province-specific economic factors include the percentage of the population ages 15 and above who have at least tertiary education, GDP per capita, and ownership structures (measured by share of GDP contributed by state-owned enterprises, collectively owned enterprises, foreign investment, and private companies). We expect that technical efficiency relates to investment in research and technology (Ahmad & Bravo-Ureta, 1996; Nishimizu & Page, 1982), but such data is not available in the 1990s. We use the annual count of patent applications as a proxy for investment in research and technology.

4.2. Investigating the role of the pollution control system and technical efficiency

We use the following reduced form to investigate the effectiveness of technical efficiency, pollution control instruments, and prices of production inputs on pollution intensity:

$$(10) S_{ijt} = \vartheta_i + \rho_i t + \varphi TE_{it} + \alpha_1 M_{it} + \alpha_2 PX_{it} + \propto_3 Q_{it} + \mu_{it}$$

where S_{ijt} is the intensity of either COD or SO_2 equivalent discharge (index by j) in province i at time t and TE_{it} is the estimated technical efficiency. Equation (10) is consistent with the three emission determinants proposed by Grossman (1995) and Grossman and Krueger (1991): (a) the scale effect that measures change in economic activity represented by the provincial economic variables such as gross output; (b) the composition effect that measures the structural economic changes, substitutions between inputs, and the tradeoff between inputs and undesirable output; (c) the technique effect that measures changes in energy/resource intensity and represented by technical efficiency. Equation (10) estimates the effect of key variables of interest on pollution intensity, including φ for technical efficiency; α's for effective levy rates of water and air pollution, the pollution quantity control targets, and pollution abatement costs.

5. The data

We rely on various China Statistics Yearbooks for province-level economic data and China Environmental Yearbooks for pollution related variables to compile a panel data set for 26 provinces and four provincial-level municipalities (Beijing, Tianjin, Shanghai, and Chongqing) in 1992-2008. The panel data for provincial output values, wage, and effective levy rates is adjusted by the provincial producer price index (PPI) and the capital input price is adjusted by the provincial price index of capital investment (PPC) in fixed assets. Both the PPI and PPC are released by China's National Bureau of Statistics.

Overall, the provincial average GDP per capita is approximately ¥2,300. The state-owned enterprises contributed more than half of industry output, followed by privately owned companies (15%), collectedly owned (10%), and foreign invested companies (7%). Approximately 20% achieve at least tertiary education. See Table A3 for the summary statistics of the economic and pollution variables.

We measure pollution intensity by COD equivalent of water pollutants and SO_2 equivalent of air pollutants per million gross industrial output values. On average, for each million output value, approximately four tons of COD equivalent, and ten tons of SO2 equivalent was discharged (see table A3). As shown in figure 2(a), the data clearly show a declining trend of pollution intensity. The COD intensity decreased by more than 80% from 10.46 to 1.55 ton per million output value from 1992 to 2003; it also decreased by more than 67% from 2003 to 0.51 in 2008. Similarly, the SO_2 intensity was almost halved, decreasing from 20.78 in 1992 to 6.16 in 2003; and more than halved from 2003 to 2.27 in 2008.

Traditionally, China is divided into four economic regions mainly based on geographical locations and economic development levels: East, Northeast, Central and West.[7] The East region is most economically developed, while the West region is the least developed. As shown in figures 2(a) and 2(b), we find a decreasing trend of pollution intensity in each economic region and significant variations of pollution intensity between economic regions, especially in the pre-2003 regime. In general, the pollution intensity was the highest in the West region, followed by the Central region, and the lowest in the East and Northeast regions. Take 2008 as an example; compared with the East region, where the average pollution intensity of COD was 0.15 tons per million real value of industrial output, the COD intensity more than doubled in the Northeast region (0.38), more than tripled in the Central region (0.53), and quadrupled in the West region (0.85). Similarly, the 2008 SO_2 intensity was the

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[7] The four economic regions are East (Biejing, Tianjin, Hebei, Shanghai, Jiansu, Zhejiang, Fujian, Guangdong, and Hainan), Northeast (Liaoning, Jilin, Heilongjian), Central (Shanxi, Anhui, Jianxi, Henan, Hubei, and Hunan) and West (Neimenggu, Guanxi, Chongqing, Sichuan, Guizhou, Yunnan, Xizang, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang).

lowest in the East region (0.72) followed by Northeast (1.47), Central (2.46), and West (3.92).

Insert Figure 2 here!

The literature has documented a significant regional disparity of the effective levy rates in the 1990s (Jiang & McKibbin, 2002; Wang & Wheeler, 2003, 2005). As shown in figures 3(b) and 3(c), we find a similar trend in the case of water pollutants in the pre-2003 regime – the effective levy rates were highest in the East region and the lowest in the West region, but the difference in the effective levy rates for air pollutants was less pronounced between regions in this regime. The post-2003 data demonstrate even wider regional disparities in the effective levy rates for both water and air pollution. For example, the levy rate in 2008 varied from ¥0.07 per ton of COD equivalent in Guangxi to ¥2.54 in Tibet, and from ¥0.11 per ton of SO_2 equivalent in Guangxi to ¥1.13 in Shanxi. However, the significant disparity in the effective levy rates does not necessarily imply that the system was ineffective. The disparity may be responsive to ambient quality and economic development, thus reflecting cost efficiency of pollution abatement (Jiang & McKibbin, 2002; Wang & Wheeler, 2005).

Insert Figure 3 here!

6. Results and Discussion

6.1. Estimated technical efficiency

Figure 4(a) and 4(b) show significant regional differences of technical efficiency. On average, technical efficiency was much higher in the Northeast region (0.51), followed by the East region (0.44), the Central region (0.36), and the lowest in the West region (0.31). **Error! Reference source not found.**(a) shows that the East region was characterized by a few highly technically efficient provinces, while the West region had provinces with high and low technical efficiency.

Insert Figure 4 here!

Following equation (9) we explore the factors that affect technical efficiency and present the results of both fixed effect (FE) and random effects (RE) models in table 2Table **2**. Both RE and FE models are estimated with robust standard errors clustered on province to account for correlation within provinces. The standard Hausman rejects the null hypothesis that an RE model provides consistent estimates as the test statistic overall equals 36.02, which exceeds the critical value at the 1% significance level (p-value = 0.000) (see table 2). However, a serious shortcoming of the standard Hausman test is that it requires the RE estimator to be efficient. Wooldridge (2002) proposes performing the Wald test using cluster-robust standard errors. The robust Hausman test also rejects the null hypothesis and favors the FE model – the Sargan-Hansen statistic (259.31) exceeds the critical value at the 1% significance level (p-value = 0.000) (see Table 2). We therefore conclude that the FE model fits the data better and mainly discuss the estimation results of the FE model.

GDP per capita is likely to be endogenous. For example, the possible omitted variable for research and development investment may affect GDP per capita. We use a panel IV fixed effects model to control for potential endogeneity of GDP per capita, where the instruments we proposed are national GDP per capita and openness to trade measured by the ratio of total imports and exports to gross GDP. Several statistical tests are performed to validate the instruments (see Table 2). First, the LM version of the Anderson canonical correlation test (Anderson, 1951) rejects the null hypothesis of under-identification, which suggests that two instrument variables are correlated with GDP per capita. Second, the Sargan-Hansen test is conducted to test for over-identifying restrictions. The result provides a strong evidence that we cannot reject the null hypothesis that the instruments are valid instruments, i.e., uncorrelated with the error term, and that the excluded instruments are correctly excluded from the estimated equation. The test results for under-identification and over-identification suggest the proposed instrument variables meet the relevance and exogeneity conditions. However, the Cragg-Donald Wald statistic (7.58) is smaller than the critical value at the 10%

significance level (19.93) and, thus, we fail to reject the null hypothesis of weak instruments.

Insert Table 2 here

The results suggest that wage has a positive effect, but capital cost has a negative effect on technical efficiency, while both effects are statistically significant at the 1% level. The above findings suggest that an increase of wage and/or a decrease in capital cost is associated with an improvement in technical efficiency. The results may partially explain that the West region is found to be lower in technical efficiency, but more labor and pollution intensive than the East region. The total number of employees per unit of gross output value and pollution intensity of SO_2 equivalent in the West region was more than triple that in the East region, but technical efficiency was lower by 28% on average. We find no statistically significant effect of the quantity control targets on technical efficiency. The effective levy rate for air pollution has a statistically significant effect on technical efficiency – the higher the effective levy rate, the higher the technical efficiency. However, the effective rate of water pollution is not statistically significant.

Table 2 also shows that GDP per capita has a positive, statistically significant effect on technical efficiency, which suggests that the more economically advanced provinces tend to have higher technical efficiency. We find that the percent of GPD contributed by different ownership structures has no statistical difference in technical efficiency with only one exception for foreign investment. Technical efficiency is lower if a greater share of GDP is contributed by foreign investment compared with that by state owned enterprises. Another surprising result is that annual number of patent applications is statistically and negatively associated with technical efficiency at the 10% level.

6.2. Estimation results on intensity of COD- and SO_2-equivalent

Based on the specification in equation (10), we conduct panel estimations of pollution intensity for COD and SO_2 equivalent. As reported in table 3, the robust Hausman test favors an FE-model for both COD and SO_2 intensity as the Sargan-Hansen test statistics exceed the critical value at the 1% significance level ($\chi^2(16)=239.15$ for COD and $\chi^2(16)=659.39$ for SO_2). Second, in both estimations we use the first lag of GDP per capita in logarithm to avoid endogeneity.

Insert Table 3 here!

We can draw the following conclusion based on the estimation results presented in table 3. First, pollution control instruments are found to be effective in reducing pollution intensity. Both the effective levy rate and the pollution quantity control targets have a negative, statistically significant effect on pollution intensity except the effective levy rate for the COD intensity (negative but insignificant). Other than these two main pollution control instruments, the regime change does not lead to statistically significant differences in pollution intensity in the 2003-2006 regime compared with the pre-2003 regime for both COD and SO_2 intensity, but the post-2006 regime is characterized by a higher pollution intensity for both COD and SO_2 compared with the pre-2003 regime. Second, technical efficiency has a negative, statistically significant effect on pollution intensity for both COD and SO_2. Third, input prices play important roles. The higher the labor cost and/or the lower the capital cost, the higher the pollution intensity. However, pollution abatement cost does not have a statistically significant effect on pollution intensity. Table 3 also suggests that a high income level is associated with lower pollution intensity, as shown by the coefficient of first lag of GDP per capita in logarithm.

7. Conclusions and policy implications

Using the provincial economic and pollution data in China, we first estimate technical efficiency using the DEA approach and then investigate the role of technical efficiency, price of production inputs, and policy instruments, namely, pollution levy and pollution quantity control, on pollution intensity. The results suggest significant regional differences in technical efficiency, effective levy rates, and provincial targets of total pollution quantity control. We also show that prices of production inputs play important roles in both technical efficiency and pollution intensity. Technical efficiency is higher if there is an increase in the effective pollution levy rate (of air pollution) or labor wage, or a decrease in capital cost. On the other hand, technical efficiency, the effective levy rates, pollution quantity control targets, and capital cost have a negative effect but wage has a positive effect on pollution intensity of both COD and SO_2.

This study offers the following contribution to the literature. First, to our knowledge it is the first study to explicitly investigate technical efficiency in pollution intensity in the context of China, as previous studies have used time trends to control for technical efficiency and changes. Second, the majority of previous studies utilize the data in the pre-2003 regime and focus on one policy instrument, the levy system. With the expansion of the data, we are able to convert pollution discharge into COD and SO_2 equivalent and investigate the effectiveness of two main pollution control instruments, the levy system and total quantity control. From this standpoint, this study provides a more complete analysis and offers broader policy implications.

This study provides the following policy implications. First, pollution quantity control effectively reduces pollution intensity but it does not improve technical efficiency. We speculate that one of the main approaches to meet the quantity control target is to shut down large polluters, which leads to reduced pollution intensity but no change in technical efficiency. On the other hand, the effective levy rates for air pollution are associated with improvement in both pollution intensity and technical efficiency. Pollution levy, a market-based instrument, may work better than command-based instruments like pollution quantity control as it gives polluters an incentive to improve technical efficiency that will lead to a long-run improvement in pollution control. Second, the prices of production inputs play important roles in technical efficiency and pollution intensity, which provide alternative channels for China to control industrial pollution. On the other hand, it also cautions the government of the unintended consequence on the environment if any policy changes are made relating to labor and capital costs.

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Table 1. *Numerical comparison of potential levy under different regimes (pre- and post-2003)*

	Actual Concentration (mg/L)	Concentration Standard (mg/L)	Pollutant Discharge [a] (kg)	Levy Amount	
				Pre-2003	post-2003 [b]
Example of a compliant firm					
COD	50	100	25,000		¥17,500
BOD	20	30	10,000		¥14,000
TSS	50	70	25,000		¥4,375
Actual Levy under different regimes				¥25,000	¥35,875
Example of a non-compliant firm					
COD	200	100	100,000	¥27,600	¥103,500
BOD	50	30	25,000	¥20,566	¥49,000
TSS	350	70	175,000	¥36,000	¥55,125
Actual Levy under different regimes (RMB)				¥36,000	¥207,625

[a] We assume the total amount of wastewater discharge is 500,000 tons in both examples. The pollutant discharge is the total wastewater discharge multiplied by the concentration of the corresponding pollutant.

[b] The conversion parameters for COD (chemical oxygen demand), BOD (biochemical oxygen demand), and TSS (total solid suspend) are one, half, and four, respectively.

Table 2. *Panel estimation results of technical efficiency*

	IVRE-tech: Panel IV RE model [1]		IVFE-tech: Panel IV FE model [1]	
	Coef.	Std.	Coef.	Std.
Effective levy rate (¥/kilogram)				
for water pollution	-0.001	(0.040)	-0.022	(0.043)
for air pollution	0.219***	(0.055)	0.200***	(0.060)
Total quantity control for SO2	0.058	(0.359)	-0.121	(0.370)
Total quantity control for COD	-0.293	(0.373)	-0.317	(0.402)
Provincial average annual wage (¥1,000)	0.011***	(0.004)	0.011***	(0.004)
Capital investment index	-0.409***	(0.141)	-0.551***	(0.182)
GDP per capita (¥1,000)	0.033	(0.022)	0.051*	(0.027)
Percent of GDP contributed by				
collectively owned enterprises	-0.257*	(0.134)	-0.169	(0.173)
privately owned enterprises	-0.129	(0.146)	0.065	(0.164)
foreign investment	-0.514***	(0.126)	-0.631***	(0.143)
other	-0.085	(0.103)	-0.058	(0.113)
% of population aged 15 who have at least tertiary education	-0.004***	(0.001)	-0.003	(0.003)
Annual no. of patent applications (1,000)	-0.011	(0.008)	-0.017*	(0.009)
Region-specific time trend: East	-0.002	(0.005)	-0.001	(0.005)
Region-specific time trend: Northeast	-0.001	(0.004)	-0.005	(0.005)
Region-specific time trend: Central	-0.009**	(0.004)	-0.007	(0.004)
Region-specific time trend: West	-0.003	(0.004)	0.002	(0.005)
Constant	0.919***	(0.161)		
No. of observations (Overall R-square)	476 (0.33)		476 (0.21)	
Standard Hausman test	$\chi^2(11) = 36.05$; P-value = 0.00			
Robust Hausman test	Sargan-Hansen statistic = $\chi^2(10) = 259.31$; P-value = 0.00			
Underidentification test: (LM version of the Anderson canonical correlation test)			$\chi^2(6)=15.22$; p-value=0.00	
Cragg-Donald Wald F-test for weak identification:				
F statistics [critical value at 10%]			7.58 [19.93]	
Overidentification test:				
Sargan-Hansen test statistics [p-value]	0.32 [0.57]		0.04 [0.84]	

Asterisks, ***, **, and *, stand for the one, five, and ten percent of statistical significance.

[1] The excluded instruments for provincial GDP per capita are national GDP per capita and opened to trade measured by the ratio of total imports and exports to the gross GDP.

Table 3. Estimation results of pollution intensity of COD- and SO2-equivalent

	Fixed-effects model for COD intensity		Fixed-effects model for SO2 intensity	
	Coef.	Std.	Coef.	Std.
Effective levy rate (¥/kilogram) (a)	-0.390	(1.330)	-8.151*	(4.528)
Total quantity control (%) (b)	-0.316**	(0.137)	-0.574**	(0.212)
2003-2006 regime	0.645	(0.633)	-0.486	(1.342)
Post-2006 regime	4.400**	(1.636)	6.034*	(3.142)
Provincial average annual wage (¥1,000)	0.465***	(0.137)	1.058***	(0.342)
Capital investment price index	-12.662**	(6.133)	-28.858**	(11.861)
Technical efficiency	-14.403**	(6.922)	-29.963*	(15.094)
Pollution abatement costs (b)	0.623	(0.710)	-0.734	(0.744)
Percent of GDP attributed by different ownership structure				
State-owned	-9.62	(6.373)	-14.427	(17.981)
Collectively owned	-12.439	(11.917)	-40.176	(25.234)
Foreign investment	-16.294	(11.070)	2.947	(32.930)
Others	-10.557	(7.186)	-26.861*	(13.645)
First lag of log(GDP per capita)	1.407	(2.488)	-14.534**	(6.467)
% of population aged 15+ having at least tertiary education	-0.081	(0.106)	-0.438	(0.339)
Region-specific time trend: East	-0.639	(0.605)	2.396	(1.490)
Region-specific time trend: Northeast	-0.777	(0.469)	1.528	(1.202)
Region-specific time trend: Central	-0.892*	(0.491)	1.765	(1.317)
Region-specific time trend: West	-1.209**	(0.546)	0.594	(1.287)
Constant	29.632	(25.822)	173.653***	(62.203)
No. of observations [No. of provinces]	476 [28]		476 [28]	
Overall r-square	0.46		0.32	
Robust Hausman test: Sargan-Hansen statistic $\chi^2(16)$ [p-value]	239.15 [0.00]		659.39 [0.00]	

Asterisks, ***, **, and *, stand for the one, five, and ten percent of statistical significance. Numbers in parentheses are standard deviations.

(a). The levy and total amount control are specific for COD- or SO_{2}- equivalent. Similarly, pollution abatement costs refer to water pollution abatement costs for COD intensity; and air pollution abatement for SO_2 intensity.

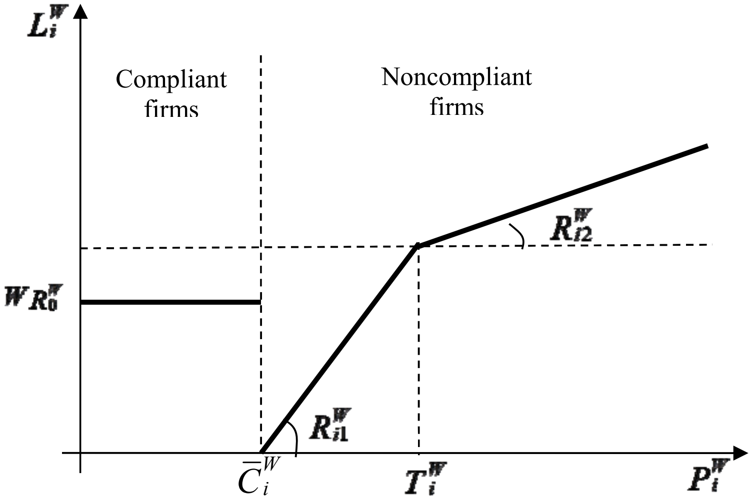


Figure 1. *An illustration of the levy system for wastewater in the pre-2003 regime*

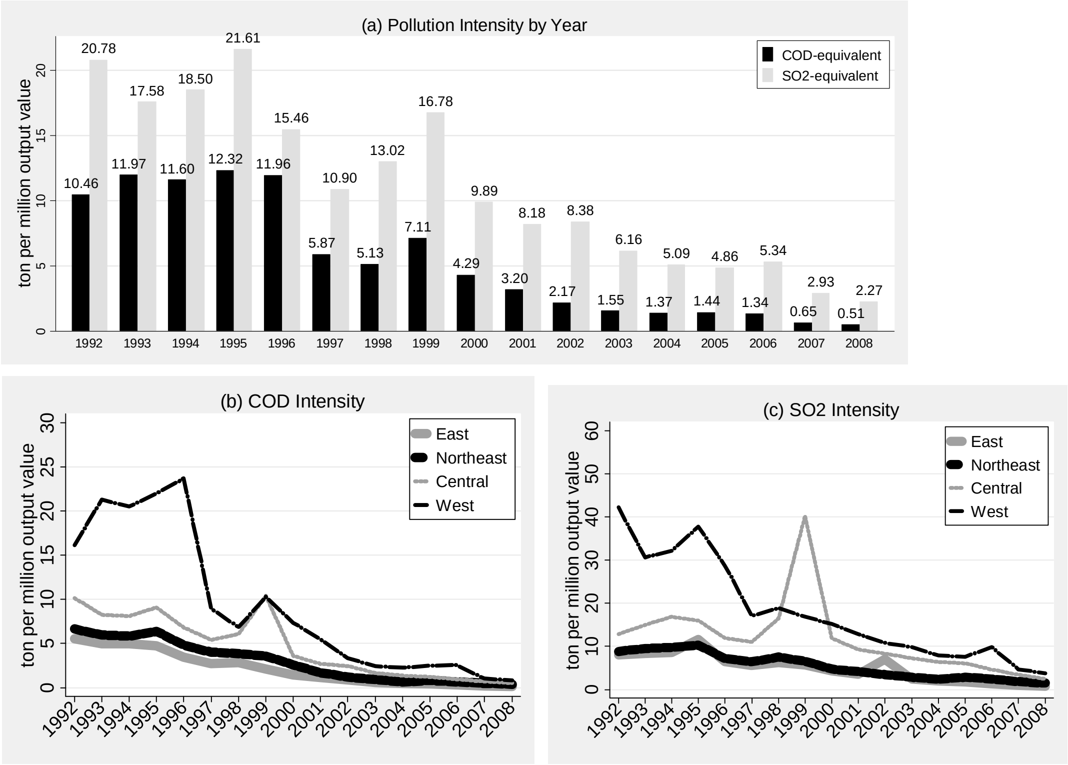


Figure 2. *Pollution intensity by year and economic region*

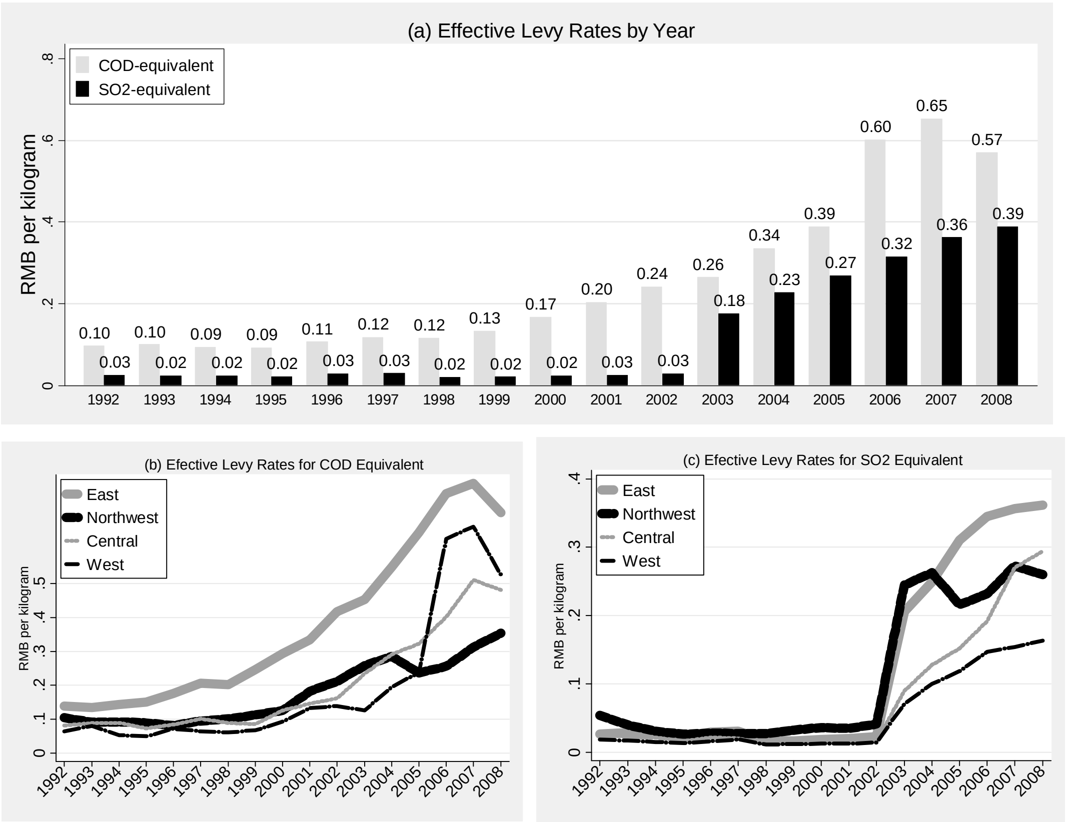
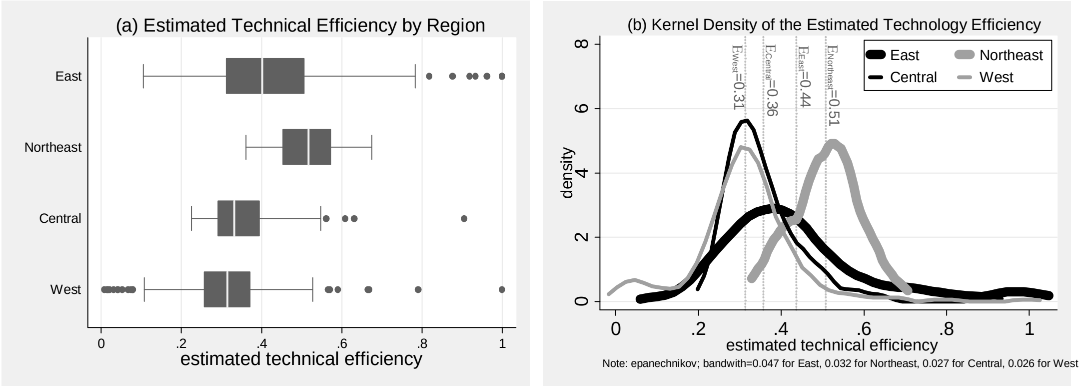


Figure 3. *Effective levy rates by year and economic region*


(a) Estimated Technical Efficiency by Region

(b) Kernel Density of the Estimated Technology Efficiency

Note: epanechnikov; bandwith=0.047 for East, 0.032 for Northeast, 0.027 for Central, 0.026 for West

Figure 4. *Estimated technical efficiency*

Online Appendix

Table A1. *Value of key parameters in calculating levy for non-compliant firms*

Water	Pollutant	T_i^W	R_{i1}^W	R_{2i}^W	$\bar{C}_i^W$ (mg/liter) by industry		
		(*ton*)	(¥/*ton*)	(¥/*ton*)	Pulp paper	Textile	Beverage
	COD	20,000	0.18	0.05	350	180	100
	BOD	30,000	0.18	0.05	70	60	30
	TSS	800,000	0.03	0.01	100	100	70
Air	Pollutant	R_i^A	$\bar{C}_i^A$				
		(*yuan*/*kg*)	(*mg*/*m*^{3})				
	SO_2	0.04	0.06				
	TSP	0.02	300				

Note: COD (chemical oxygen demand), BOD (biochemical oxygen demand), and TSS (total solid suspend) are three common water pollutants; while SO_2 (sulfur dioxide) and TSP (total suspend particulate) are two common air pollutants.

Table A2: *China pollution control instruments*

Command-control Instruments	Economic Incentives	Voluntary Instruments	Public Disclosure
Pollution discharge limit, based on allowable pollutant concentration	Pollution Levy	Environmental labeling system	Clean-up campaigns
Mass-based controls on total provincial discharge	Pollution Report and Discharge permit system[6]	Cleaner Production	Assessment of Urban Envi. Quality (AUEQ)[8]
Environmental Impact Assessment (EIA) [1]	Non-Compliance Fine	Environmental model cities	Envi. Awareness Campaigns
Three Synchronization Policy (TSP) [2]	Sewage tariff regulation	Envi. responsibility system[7]	Air Quality Index Disclosure
Limited Time Treatment (LTT) [3]	Sulfur emission fee	ISO 14000 system	
Centralized Pollution Control (CPC) [4]	Emission trading (experimental)		
Two compliance policy[5]	Subsidies for energy-saving products		
Environmental compensation fee	Credit Restrcitions to heavy polluters		

[1] EIA was first introduced in Clause 6 of the 1979 Provinsional Environmental Protection Law and was formally required to carry out by an administrative order from National Environment Projection Commission in 1981. All new firms or new production project are required to complete an EIA depending to the nature and size of the proposed project/firm.

[2] The TSP requires that the design, construction, and operation of a new production facility be synchronized with the design, construction, and operation of appropriate waste treatment facilities. A new production facility or a production line cannot be put into operation without a certification of the TSP issued by from SEPA. Jing and Mckibbin (2002) argues that this policy instrumnet may not contribute to environmental protection as firms may shut down the waste treatment facilities after granted the certification.

[3] The LTT policy orders a limited time for non-compliant, heavy polluting firms to treat their pollution to meet the standard and come into compliance. If the requirement is not met, the firm will be orderedt o temporarily halt its production, or face shut-down or relocation.

[4] Cnetralized Pollution Control provides economies of scale and is cost effective and, thus, is greatly encouraged (Jiang & McKibbin, 2002).

[5] Two Compliance Policy requires firms in compliance with both discharge standards and ambient standards. This instrument suggests the emphasis shift from pollutant concentration-based control to pollutant mass-based control.

[6] Pollution Report and Discharge Permit System requires individual firms report their pollution discharge to local environmetnal authorities and the authorities then issue a pollution discharge permit to each firm. No market has emerged to trade the discharge permit in Chian.

[7] The government leaders at the different levels sign an environmental protection control contract to raise their environmental awareness.

[8] AUEQ is conducted annually and the results are assessble to the public through different channels including media. The aim is to impose public pressure on local government to improve environmental quality and to raise environmental awareness among the public.

Table A3. *Summary statistics of dependent and independent variables*

Variables	mean	standard deviation	Min.	Max.
Pollution intensity (ton per million output value)				
COD intensity	4.23	6.17	0.03	77.66
SO_2 intensity	10.21	14.18	0.23	183.53
Production input prices				
Annual wage (¥1,000)	8.71	7.29	1.75	49.17
Price index of capital investment	1.03	0.12	0.76	1.31
Effective levy for water pollutant (¥/kilogram)	0.23	0.24	0.01	1.38
Effective levy for air pollutants (¥/kilogram)	0.12	0.18	0.00	1.13
Annual number of patents granted (1,000)	7.35	14.53	0.09	128.00
Percent of pop. aged 15 and up have at least tertiary education	19.65	10.20	6.50	60.20
Share of gross output value contributed by				
state-owned enterprises (SOE)	0.50	0.17	0.14	0.91
collectively owned enterprises (COE)	0.10	0.08	0.00	0.41
foreign investment	0.07	0.07	0.00	0.29
privately owned enterprises	0.15	0.06	0.01	0.35
Other	0.18	0.15	0.00	0.55
Openness to trade: (import + export) / GDP	0.35	0.72	0.03	12.80
Gross industry output value (¥1,000,000,000)	188.23	270.68	3.71	2084.88
GDP per capita (¥1,000)	2.38	2.78	0.08	19.81

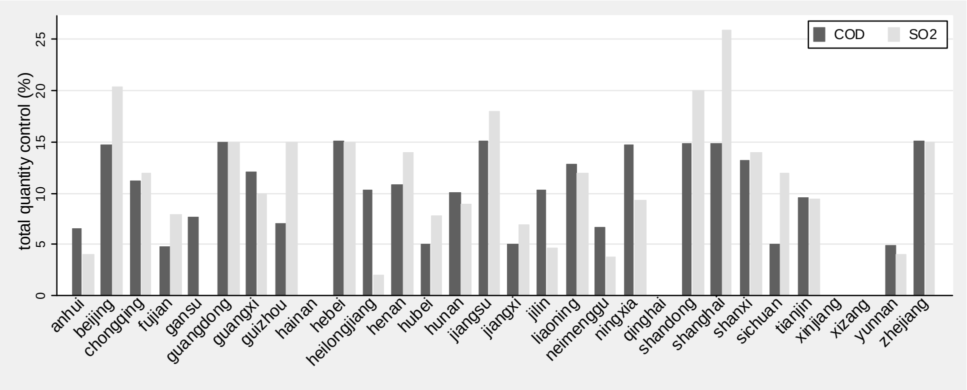


Figure A1*: Total quantity control target for each province*