Enforcement of Pollution Taxation in China*

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Abstract

We investigate how plants react to inspections conducted by environmental authorities under the pollution taxation regulation in China. Contrary to the studies in US/Canada (Magat and Viscusi, 1990; Laplant and Rilstone, 1996) or previous studies in China (Dasgupta et al. 2001), we find inspections increase plants' self-reported pollution by 8.26%. We provide a model to analyze plants' strategic reactions to the pollution taxation regulation in China. The model concludes that under the specific regulation plants' actual pollution might be going up with the increase of inspections. Our study provides a key policy implication that inspections by environmental authorities in China are mainly effective on verifying plants' self-reported pollution but not on reducing their pollution. In order to control pollution, a reform of the regulation is necessary.

JEL Classification: C33, C81, K32, K42, Q28.

Keywords: Enforcement; Inspections; Pollution taxation

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1 Introduction

For the decades since the beginning of the 1970s, governments of developed and developing countries have enacted a large number of environmental regulations in order to reduce industrial pollution and improve environmental quality. However, imposing regulations on plants' pollution does not necessarily lead pollution to fall and environmental quality to improve. Environmental regulations may turn out to be ineffective, if they are not enforced. In other words, enforcement brings regulated agents (polluters) to comply with regulations.

In most countries, enforcement of environmental regulations involves plants' self-monitoring, that is, plants have to self report their pollution at regular interval to environmental agencies[1]. However, plants' self-reporting is not generally accurate, or even sometimes greatly deviates from their actual pollution. Hence, in order to improve plant's compliance with environmental regulations, environmental agencies need send inspectors to plants to check their pollution on-site. A question, which therefore arises here, is whether inspections by environmental authorities make plants self-reporting truthfully, or they make plants reduce their actual pollution, or both.

This paper studies how polluters react to environmental authorities' inspections under China's pollution taxation. In other words, we want to answer whether the inspections, conducted by China's environmental agencies, are effective on reducing plants' pollution. We answer the question from both a theoretical and an empirical perspectives. Our study provides a key policy implication: inspections are ineffective on reducing plants' actual pollution. In order to control pollution, a reform of the regulation is necessary.

The approach of the enforcement-compliance literature takes its point of departure from the theory of the economics of crime as developed by Becker (1968). Downing and Watson (1974), Harford (1978), and Storey and McCabe (1980) first applied the Becker model in the environmental arena. More recently, there has been a rapid growth in the theoretical and empirical

[1] It is commonly accepted in the literature that self reporting improves regulated agents' compliance with regulations (see Kaplow and Shavell, 1994). Self-reporting has been widely adopted in most countries.

literatures on these issues[2].

Magat and Viscusi (1990) (henceforth MV) and Laplante and Rilstone (1996) (henceforth LR) have respectively estimated the impact of inspections on plants' reported pollution of the pulp and paper industry in the United States and Canada, where pollution standards are imposed. These authors agreed that in their samples plants' reported pollution reflect their actual pollution to a large extent. MV have shown that inspections reduce permanently the level of pollution of plants by approximately 20%. LR concluded that not only inspections but also the threat of inspections reduce pollution by approximately 28%. More recently, Nadeau (1997) has shown that inspections significantly reduce the duration of plants' violation of air pollution standards in the pulp and paper industry in US. Other studies extend the analysis to include other enforcement actions. Shimshacka and Ward (2005, 2007) used data again from pulp and paper industry in US to analyze the impact of a fine for water pollutant violations. All of these studies confirm theoretical prediction that plants' actual pollution is a decreasing function of the level of enforcement under pollution standards (see Harford, 1978). Therefore, inspections by environmental agencies in US/Canada induce plants' actual pollution close to the standards.

The environmental regulation in China is very different from the ones in US and Canada. Although there are pollution standards in China, plants can just pay taxes if their pollution are above standards. Dasgupta et al. (2001) (henceforth DL) has examined whether inspections have an impact on China's polluters' environmental performance. Their data set includes both plants paying and those not paying pollution taxes. They have found that plants' reported pollution decreases by a very small amount with inspections. There are also other studies in this context on China's cases. For instance, Wang et al. (2002) have shown state-owned firms have more bargaining power than private firms in enforcement. Wang and Wheeler (2005) found plants' compliance with regulations is sensitive with plants' characteristics (ages, locations and so on).

We first integrate China's pollution taxation into the model introduced

[2] For a recent survey of the literature, see Cohen (1998).

by Macho-Stadler and Pérez-Castrillo (2006) (henceforth MP). Our model predicts that under the particular China's taxation system, plants' actual pollution firstly decreases and then jumps to a higher level as enforcement becomes more rigorous. Reported pollution is, on the contrary, an increasing function of enforcement. Furthermore, the gap between the actual and reported pollution always narrows with increasing levels of enforcement.

We then study empirically how inspections explain plants' reported pollution. We collect and adopt a unique data set, where only plants that pay pollution taxation are included. To our knowledge, the present paper is the first empirical work to analyze how plants react to environmental authorities' inspections when they pay pollution taxes. Our empirical results indicate that with pollution taxes, inspections by environmental agencies significantly and positively increase plants' reported pollution by 8.26%. The results are consistent with the theoretical predictions. The results also suggest that plants generally underreport their pollution and more importantly that inspections are not effective on reducing plants' pollution in China.

The results differ greatly from the ones of MV and LR. As we mentioned before, they found that inspections reduce plants' reported pollution by a very large margin. They treated plants' self-reporting as their actual pollution, while we treat plants' reported pollution just as it is. The institutional difference between China and US/Canada explains well the difference. In particulars, US and Canada implement pollution standards while China uses pollution taxation. Other factors, such as penalties for fraud reporting, environmental authorities' inspection strategies and so on, also explain the observation.

The rest of the paper proceeds as follows. In Section 2, we present China's environmental regulations in detail. In Section 3, a model analysis, integrating China's specific environmental regulations, is provided. In Section 4, we present and describe our data set. In Section 5, empirical models and results are presented. Section 6 concludes. Theoretical proof can be found in Appendix I.

2 Environmental Management in China

China's industrial growth has been extremely rapid. Since the 1980s, industrial output has increased by more than 10% annually. Industry has become the largest sector in China's economy and now accounts for approximately 50% of total China's GDP. However, accompanying this rapid growth, the environmental damage has become a serious problem and a bottle-neck for sustainable development. Almost one third of China's waterways are near biological death from excessive discharge of organic pollutants and five of seven rivers have been badly polluted. In many urban areas, atmospheric concentrations of pollutants such as suspended particles and sulfur dioxide routinely exceed World Health Organization safety standards by very large margins (Dasgupta et al., 1997; World Bank, 1997). Industry is the primary source of water and air pollution in recent years. China's State Environmental Protection Agency (SEPA) estimates that industrial pollution accounts for over 70% of the nation's total emissions of pollution (SEPA, 1996).

Since the late 1970s, Chinese national environmental regulations have been designed to reduce industrial pollution and improve environmental quality in a way that is consistent with the average level of social development. The Environmental Protection Law (EPL) was firstly adopted (on a trial basis) in 1979 by China's legislative authority and was officially enacted in 1989. In accordance with the EPL, a series of pollution control regulations were implemented and enforced by environmental administration authorities. The pollution control regulation has been amended several times since 1982[3]. However, it always mainly involves a pollution tax charge that is called *pollution levy system*.

2.1 Design and development of the levy system

Before 1993, the levy system formally required that any plant pay a fee only on the quantity of effluent discharge that exceeded the legal standard. Moreover, the pollution levy was actually paid only on the pollutant that

[3] Regulations has been amended in 1982, 1991, 1993 and 2003

exceeded its standard by the greatest amount, but not on all the pollutants that exceeded their standard. After 1993, levies at lower rates have also been imposed to those plants who only discharge within-standard water and air emissions. Finally, since 2003, plants are required to pay levies on the pollutants with the three greatest amount, and the levy rates have increased largely. The new regulation gives plants stronger incentives for pollution control.

Given that our data set is based on plants' pollution of wastewater for the year 2002, we mainly explain the pollution levy system in 2002 for wastewater. As reported before, the only qualitative difference with respect to the system currently in use is that plants only required to pay taxes on one pollutant, while they must pay on up to three pollutants nowadays.

China's pollution levy system is a two-tier pollution charge system, with uniform rates for within-standard emissions and higher, but de-escalating rates for above-standard emissions. If every pollutant emitted by a plant is below the corresponding standard, the plant pays within-standard levy total amount of wastewater discharges[4], otherwise, plants pay above-standard levy.

The above-standard levy is calculated with repect to those pollutants emitted by plants above their corresponding standards. Now, consider a plant j emitting M water correlated pollutants that are above the corrsponding standards, namely, for each pollutant i ($i = 1, ...M$), the concentration (C_{ji}) is greater than the corresponding legal standard (C_i^*). The above-standard levy is calculated as follows:

$$L_j = \max\{L_{ji},\, i = 1, ...M\}$$

where

$$L_{ji} = \begin{array}{ll} R_{2i}P_{ji} & \text{for } P_{ji} \leq T_i \\ L_{0i} + R_{1i}P_{ji} & \text{for } P_{ji} > T_i \end{array}$$

where L_{ji} is the estimated levy to be paid by plant j on pollutant i; P_{ji} is the discharge factor of pollutant i calculated as $W_j \frac{C_{ji} - C_i^*}{C_i^*}$, where W_j is the total amount of wastewater discharged by plant j; T_i is the threshold factor that determinates the levy rate adopted; R_{2i} is levy rate applied when

[4] Since 1993, the standard fee for within-standard wastewater discharges has been ¥0.05 per ton. Within-standard charges have also been assessed on SO2 emissions since 1996. $USD\$1 \approx RMB¥7.5$

the discharge factor P_{ji} is below the threshold while the levy rate R_{1i}, with $R_{1i} < R_{2i}$, is applied for above-threshold pollution; and $L_{0i} = [R_{2i} - R_{1i}]T_i$ is a fixed payment that makes the levy function continuous[5]. The potential levy L_{ji} is calculated for each pollutant i; the actual levy L_j is the greatest of the potential levies.

The levy function takes into account both the concentration of the hazardous pollutant and the volume of discharge wastewater, since it calculates the discharge factor (P_{ji}) based on both total wastewater discharge and the degree to which pollutant concentration (C_{ji}) exceeds the standard (C_i^*). The standard (C_i^*) is jointly set by the central and local governments, and it is different by industry and waterway where the wastewater is discharged. Both levy rates (R_{1i},R_{2i}) and the threshold factor (T_i) are set by the central government and vary by pollutant, but not by industry or region[6].

The levy system fails to provide plants a strong incentive to control pollution. Firstly, the levy system integrates both pollution standards and taxes. Pollution falling short of standards can be compensated by monetary payment, which makes standards soft constrains of plants' polluting behavior. Secondly, the levy system only requires plants to pay levies on the pollutant that exceeds its standard by the greatest amount; therefore, plants may only

[5] The formula is calculated on monthly base.

To illustrate, we compute COD and TSS levies for a plant whose discharged water concentrations are $140\mu g/l$ for COD (local standard$= 100\mu g/l$) and $140\mu g/l$ for TSS (local standard$= 70\mu g/l$). The relevant ratio $(C_{ji} - C_i^*)/C_i^*$ is 0.4 for COD and 1 for TSS. The plant's discharge of wastewater W is $100,000$ tons. Therefore, $P_{COD} = W * 0.4 = 40,000$ and $P_{TSS} = W * 1 = 100,000$. The tax rates for the two pollutants are $R_{1COD} =$ ¥$0.05/ton.time$; $R_{2COD} =$ ¥$0.18/ton.time$; $R_{1TSS} =$ ¥$0.01/ton.time$; $R_{2TSS} =$ ¥$0.03/ton.time$;. The regulatory threshold parameters for the two pollutants are $T_{COD} = 20,000$ and $T_{TSS} = 800,000$, and the fixed payment factor is $L_{0COD} = \$2,600$ and $L_{0TSS} =$ ¥$16,000$. Since $P_{COD} > T_{COD}$ and $P_{TSS} < T_{TSS}$, applying the formula, the potencial levies are $L_{COD} = L_{0COD} + R_{1COD}P_{COD} =$ ¥$4,600$, and $L_{TSS} = R_{2TSS}P_{TSS} =$ ¥$3,000$. Since the levy for COD is higher, the plant's water levy charge is ¥$4,600$.

[6] The levy formula for air pollution is simpler. The within-standard levy is exactly the same as wastewater levy. As for above-standard air pollution levy, unlike the water levy, the air levy is assessed on the absolute, rather than percentage, deviation from the concentration standard. For firm j and pollutant i, the potencial levy is $L_{ji} = R_i V_j (C_{ji} - C_i^*)$, where R_i is the levy rate; V_j is the total volume of air emission; C_{ji} the pollutant concentration and C_i^* the concentration standard. Again, a firm is assessed only the highest of its potential levies.

care about the pollutant they are paying levies for but they do not have any incentive to reduce other pollutants. Third, in some cases a plant even pays more levies when its emission is up to the standard[7]. Finally, the levy system is not compatible with the principles of environmental economics, since the more pollutants a plant emit, the cheaper the levy rate the plant is subject to.

2.2 Implementation of the levy system

Chinas' State Environmental Protection Administration is the state level agency that is empowered and required by law to implement environmental policies and enforce environmental laws and regulations. In practice, local (municipality and county/district) environmental protection bureaus (EPBs) are responsible for many activities pertaining to the actual implementation of the environmental regulations. There are EPBs in all the various districts of the municipalities. Municipal EPBs are mainly in charge of relatively big polluters and district EPBs deal with small polluters. Although legally responsible for SEPA, local EPBs heavily depend on local governments in financial budgets and organization structures.

All polluters are required to self-report their pollution to environmental authorities by providing the information in the following two categories: (1) basic economic information (sector, major products, raw materials, number of employees and so on); (2) pollution emitted (volume of wastewater, air or solid wastes discharge; pollutant concentrations). The polluters' reports are checked by environmental regulation agencies in several ways, including consistency between materials and output; consistency with historical data; monitoring and inspections. Once reports are verified, levies are calculated

[7]In the same framework as the example developed in footnote 5, assume that the plant's discharged water concentrations are $90\mu g/l$ for COD (local standard= $100\mu g/l$) and $65\mu g/l$ for TSS (local standard= $70\mu g/l$). Hence, the wastewater discharged comes up to the standard. Again the plant's discharge of wastewater W is $100,000$ tons. In this way, the plant pays the within standard levy: $W * ¥0.05/ton = ¥5,000$. Compared with the one we calculate in the footnote 6, it is obvious that the within-standard levy is even higher than the above-standard levy ($¥5,000 > ¥4,600$), in this case.

In the lately amended system, these cases have been eliminated.

and collected by local regulation authorities monthly or quarterly[8].

The detailed procedures of implementing the levy system are as follows. At the beginning of a year, plants have to register with environmental authorities by providing the predicted volume of emissions in the coming year (according to the usual production procedures). Environmental authorities verify the registration reports and then issue discharging pollution permits to plants. During the year, plants are required to modify their reports, when their actual emissions are different from the ones that they predict at the beginning of the year. Environmental authorities verify plants' reports by conducting field inspections. At the end of each quarter, based on plants' reports and inspections, authorities notify the 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 first estimation) and if they are caught by the authorities, plants are liable to penalties, where they are required to pay the evaded levy and the between 100% and 300% extra for penalties. When a plant badly underreports and is caught, besides the regular penalty it faces a fixed amount of additional penalty. The total monetary penalty should not exceed the ceiling of $¥100,000$ (around 13,333 US dollars). Although other non-monetary penalties are also available such as revoking discharge licenses and shutting down facilities, they are rarely used. Hence, the penalty mainly involves a financial cost with a ceiling.

Given this self-reporting system, these specific procedures of self-reporting, and a monetary penalty with a ceiling for fraud reporting, plants do not have strong incentives to report their emissions truthfully.

3 Model analysis

In this section, we build an imperfect compliance model to understand plants' behavior under China's specific environmental levy system. In the model, we integrate three main factors of the levy system introduced above: environ-

[8]It varies with regions.

mental taxes with decreasing marginal rate and with self-reporting, inspections' verification and monetary penalties for false reporting. We allow plants to make decisions on their actual and reported emissions. We also assume that plants are risk-neutral[9]; more importantly, we assume plants could adjust their decisions to the monitoring and inspections occurred to them as we mentioned that plants can strategically report their pollution. With these characteristics, we use the model originally introduced by Harford (1978) and extended by MP recently. Our model differs from MP in that we integrate China's levy system with nonlinear taxes (two different tax rates) instead of a linear tax (a uniform tax rate). This gives rise to novel, interesting results.

3.1 Model setting

A plant's decision concerning actual or reported emissions has two dimensions: the volume of waste water (W) and the concentration (C) of the hazardous chemicals of wastewater. For a given level of total pollution, a plant equalizes the marginal costs of abating the volume of wastewater and that of decreasing the concentration of pollutants. Therefore, for simplicity and without loss of generality, we assume that a plant's decisions are only on the total volume of pollution (namely, W times C). Moreover, we concentrate the analysis on the decisions concerning a single pollutant, because plants are assumed to care only about the major pollutant they are paying levies for.

A plant decides how much to emit and how much to report. We denote by E the plant's actual emissions and by Z the self-reported emissions. In accordance with the levy system, if a plant's reported emission Z is lower than the threshold T, its levies are calculated by ZR_2, otherwise it pays levies as $ZR_1 + L_0$. T and L_0 are the parameters in the levy system. R_1 and R_2 are corresponding tax rates.

Given that the plant may underreport its emission, it is audited with a probability ρ. If a plant underreports its emission and if it is caught, then

[9] Risk aversion, or wealth constraints possibly leading to bankruptcy, may be important in some cases. However, since penalties are mainly money-oriented fines, we can generally agree firms are risk-neutral.

it has to pay a penalty, which is measured by a function $\theta(\cdot)$. Hence, the expected penalty is given by $\rho\theta(\cdot)$. The penalty function $\theta(\cdot)$ is increasing and convex in the underreported emissions (namely $E - Z$), that is $\theta(0) = 0$ and $\theta''(x) > 0$ for $x > 0$. We also assume $\theta'(0) > R_2$ ($\theta'(0) > R_1$ as well, since $R_2 > R_1$) because the penalty should be more expensive than the evaded taxes. The convexity of the penalty function reflects the fact that when a plant badly underreports and is caught, the marginal penalty is increasing with the emissions less reported by plants. We don't take into account the ceiling. Also, we express the penalty as a function of underreported emission. It is difficult to tell whether penalties are actually based on underreported emission or on evaded emission taxes. This differs from case to case. To treat the penalty as a function of misreported emission makes the analysis more simple. However, the simplification does not influence the essence of the main results.

We also define $g(E)$ as plants' revenue function, which is concave and increasing in E. We denote by E_1^* the level such that $g'(E_1^*) = R_1$, and similarly for E_2^*. We have $E_2^* < E_1^* < \overline{E}$, where $\overline{E}$ is the emission level the firms would decide if there was no enforcement, defined by $g'(\overline{E}) = 0$.

For a given auditing probability ρ, the plant's maximization problem is therefore can be writen as:

$$\begin{gathered}\max_{E,Z} E\pi(\rho, E, Z) \\ \text{s.t. } Z \in [0, E]\end{gathered}$$

where

$$E\pi(\rho, E, Z) = g(E) - ZR_2 - \rho\theta(E - Z) \text{ if } Z \leq T \text{ and}$$

$$E\pi(\rho, E, Z) = g(E) - ZR_1 - L_0 - \rho\theta(E - Z) \text{ if } Z > T.$$

If the solution is interior, the first-order conditions are:

$$\begin{aligned}\frac{\partial E\pi}{\partial E} &= g'(E) - \rho\theta'(E - Z) = 0, \\ \frac{\partial E\pi}{\partial Z} &= -R_i + \rho\theta'(E - Z) = 0\end{aligned}$$

where $R_i = R_2$ if $Z \leq T$ and $R_i = R_1$ if $Z > T$.

3.2 Model results

As a benchmark, we first present the results when there is only one tax rate. Consider the specific case of the above model, in which plants only face one tax rate (let us say R, and correspondingly define E^* by $g'(E^*) = R$) no matter how much emission they reported. The following proposition describes the optimal plants' behavior as a function of audit probabilities:

Proposition 1 (MP) *For a given tax rate R, audit probability ρ, and penalty function $\theta(\cdot)$, the optimal emission and report decisions (E°, Z°) for a plant are:*

(a) If $\rho = 0$, then $E^\circ = \overline{E}$ and $Z^\circ = 0$.

(b) If $\rho \in (0, \frac{R}{\theta'(E^*)})$, then $E^\circ \in (E^*, \overline{E})$ as defined by the following equation and $Z^\circ = 0$:

$$g'(E^\circ) - \rho\theta'(E^\circ) = 0. \tag{1}$$

(c)If $\rho \in [\frac{R}{\theta'(E^*)}, \frac{R}{\theta'(0)})$, then $E^\circ = E^*$ and $Z^\circ \in [0, E^*)$ as defined by the following equation:

$$-R + \rho\theta'(E^* - Z^\circ) = 0.$$

(d)If $\rho \geq \frac{R}{\theta'(0)}$, then $E^\circ = E^*$ and $Z^\circ = E^*$.

Proposition 1 states that, with the increasing pressure of environmental enforcement, the plant first reduces actual emission until the level where the marginal gain from emission is equal to the tax rate, and then more pressure will lead the plant to report more emission. Once the plant reports the true emission level, increasing auditing probability would be useless.

Proposition 1 is described in Figure 1. The horizontal axis represent, the audit probability; the vertical axis represents plant's actual and reported emissions. The continuous line depicts the plant's optimal emission while the dashed line represents the plant's optimal reported emission. The letters in parentheses mark the different regions defined in the proposition. We can

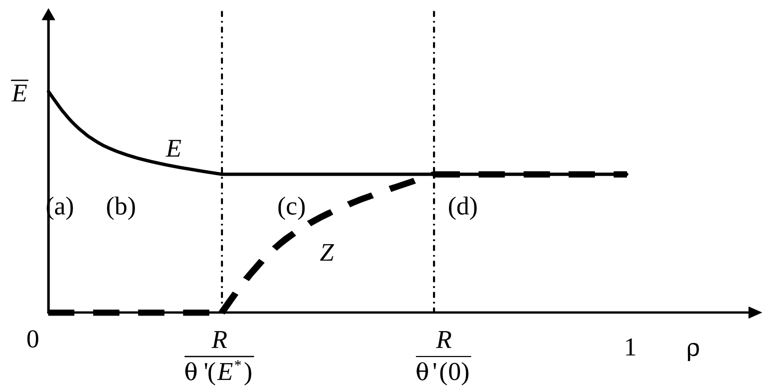

Figure 1: Emission and report with a linear tax

easily conclude that the actual emission is nonincreasing and the reported emission is nondecreasing in the audit probability. Moreover, the gap between real emission and reported emission is always decreasing in the audit probability for $\rho \leq R/\theta'(0)$.

We now turn to the analysis of plants' optimal behavior under China's specific levy system, which involves two different tax rates. In the proposition, we distinguish two types of plant:

Type 1: plants such that $E_1^* \leq T$; or $E_2^* \leq T < E_1^*$ and $g(E_2^*) - R_2E_2^* \geq g(E_1^*) - R_1E_1^* - L_0$.

Type 2: the rest of plants.

Proposition 2 *Under the China's levy system, the optimal emission and report decisions for a plant are:*

Type 1: the same as the one described in Proposition 1 *for $R = R_2$.*

Type 2: there exists a critical auditing probability $\rho^* \in \left(\frac{R_1}{\theta'(E_1^*)}, \frac{R_1}{\theta'(0)}\right)$, such that for $\rho < \rho^*$, the plant makes decisions according to $R = R_2$; for $\rho \geq \rho^*$, the plant makes decisions according to $R = R_1$.

Under the China's system, a plant adapts to the cheaper environmental tax rate only if its reported emission level is higher than the threshold T. If a plant is better off emitting (and reporting) less than T under perfect enforcement, it will also report less than T (even if its actual emissions may

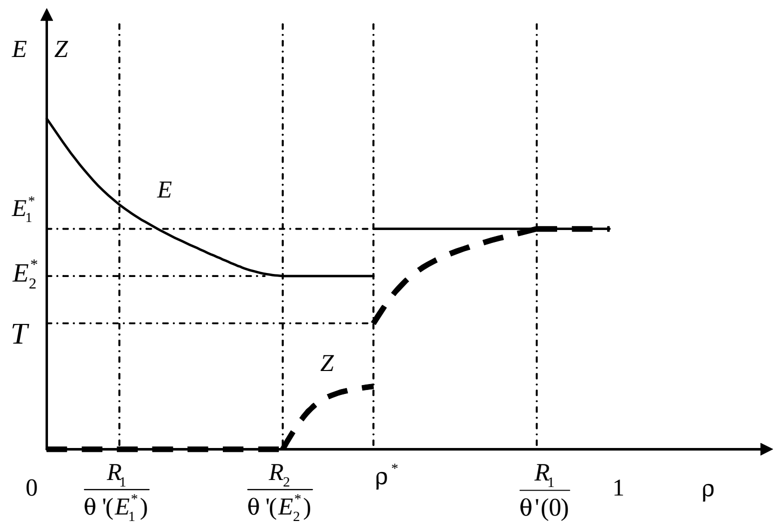

Figure 2: Emissions and report under China's system in region 2

be larger) under imperfect enforcement. This happens when the parameters are in type-1, where the plant behavior as if there was only the higher rate R_2. Otherwise (type-2), there exists a critical audit probability ρ^*, such that, for any audit probability lower than ρ^*, plants make the optimal decisions corresponding to the expensive tax rate while any audit probability higher than ρ^* leads the plant to adapt to the cheap tax rate.

Figure 2 describes a type-2 plant's behavior. Again the continuous line describes the plant's optimal actual emission while the dashed line represents the plant's optimal reported emission. The cutoff audit probability ρ^* is characterized as the audit probability that makes plants emit E_1^* and report T when it is subject to R_1, namely, $\rho^* = \frac{R_1}{\theta'(E_1^*-T)}$. The cut-off ρ^* may be smaller than $\frac{R_2}{\theta'(E_2^*)}$. In this case, the plant would first report zero emission and then jump directly to report T with increasing audit probability. It is also worth knowing that ρ^* is greater than $\frac{R_1}{\theta'(E_1^*)}$, namely there always exist audit probabilities for which adapting to R_2 is optimal. The following corollary summarizes plants' behaviors when they are of type 2.

Corollary 3 *(1) For the type-2 plants, a plant's actual emission is decreasing in ρ until it jumps to a higher emission level at the critical level ρ^*. A* *plant's reported emission is nondecreasing, with a jump at ρ^*.*

(2) The gap between actual and reported emissions is always decreasing with a jump at ρ^*.

In this section, based on the characteristics of China's levy system, we have explored the optimal plants' behavior. We have shown that, under the nonlinear tax system, plants' actual emissions firstly decrease and then jump to higher levels while reported emissions are nondecreasing with increasing enforcement. In the following sections, we use plant-level data to analyze the impact of enforcement (inspections) on plants' environmental performance.

4 Data description

The data used in the current empirical analysis have been supplied by the Fuzhou Environmental Protection Bureau (FEPB). Fuzhou is the capital city of the Fujian province, which is located on the southeast part of China. Fuzhou's GDP was ¥ 31,582 (around US$4,210) per capita in 2003, ranked 21 among 658 Chinese cities. Over the course of the last decade, Fuzhou's industrial output increased at an average rate of 12% annually. Fuzhou's eleventh Five-Year Plan (2006-2010) calls for further development of the food, medicine, chemical, automobile and textile industries. However, as a result of this rapid expansion, both air and water ambient quality has deteriorated. For instance, over 25% rain is acid with PH value between 5.0 and 5.6 in 2006.

We sample the plants according to the following criteria: 1) they pay levies according to COD emissions in the year 2002; 2) they belong to food, chemical, paper or medicine sector 3) they are supervised by the FEPB. We have sampled those plants that pay levies with respect to COD emissions since COD is the pollutant that major plants (emit and) pay levies for, and we expect that those plants' decisions on the pollutant of paying levies may be more sensitive to inspections. We concentrate on the four sectors that include the plants that are large polluters of COD.

Our data set is different from the ones adopted in DL and in Wang and Wheeler (2005), who also study plants' environmental performance with China's levy system. Compared with the former, we use quarterly based observations instead of annual data and we also add the variable of value of output. Moreover, we only consider those plants that pay levies. In the latter paper, the authors did not include inspections in their analysis.

Table I displays some descriptive statistics of the data set. It involves 137 plants' emission and production information for the year 2002. The variables such that value of output, COD/TSS concentrations and discharges, levy rate, times of inspections and times of citizens' compliant, are quarterly based. Although the rest of variables, number of workers, plants' age, sector and ownership, are annual based data, we simply treat them as the quarterly ones because they are not expected to notably change within a year. The variable of the value of output is collected from the Fuzhou Bureau of Statistics because FEPB can only provide the annual value of output and we expect the variation of plants' quarterly value of output to be an explanatory variable for quarterly change in plants' pollution.

We now comment on some of statistics in the Table I. Note first that the quarterly average times of inspections are 2.19 per plant. In fact, almost all plants suffer at least one field inspection in a quarter and one plant had inspections up to 8 times. Note also that we integrate two kinds of pollutants in our data set: one is plants' COD emissions for which they pay pollution levies; the other is their TSS emissions that no plants pay pollution levies for. Plants' TSS discharges (concentrations) are shown to be much less than their COD emissions (concentrations). There are above 60% of the plants paying levies according to the low tax rate, so they report (and they certainly emit) COD emissions above the threshold level. We also include citizens' complaints in our data set. Apart from field inspection activities, complaints made by citizens regarding environmental incidents may trigger inspections and furthermore make plants further comply with environmental regulations. Moreover, the average quarterly value of output is 44.1 millions yuan (around 5.88 millions US dollars) and the average number of employees is 443. Chemical is the largest sector plants in our sample belong to. Finally, although collective plants are the most represented in our sample

(45%), state-owned and joint venture plants are also well represented.

A question which naturally arises with self-reporting is whether the plants accurately report their emissions levels. To some extent, the question is out of observation and it can only be answered by those who make reports: the plants themselves. In view of China's levy system, we expect that plants have strong incentives to report inaccurately. First, pollution taxations are generally imposed in China. Compared pollution standards, pollution taxations make plants have strong financial incentives in balancing the costs of true report (taxes) and possible fines (see also Wang and Wheeler, 2005). Second, as for the legal liabilities for inaccurate reporting, plants usually only face a limited monetary penalty. Hence, plants can fix their cost of noncompliance in advance. Finally, the procedures of self-reporting provide plants some room for underreporting. According to employees of FEPB, most plants' reports at the beginning of the year are significantly below the ones they finally pay for. Although the emission variables in our data set come jointly from self-reporting and inspections' verification, it should not be treated as real emissions. Therefore, we strongly suspect that emission variables in our data set is not plants' accurate emissions and we just treat them as self reported emissions. We will further argue these points by using our econometric results.

Table I Descriptive Statistics of Sample
(Quarterly Data 2002:1–2002:4)

Variable(Quarterly Base)	Mean	Standard Deviation
Value of output (10 millions yuan)	4.41	6.52
Number of employees	443.28	321.66
COD discharge (Tons)	25.37	53.61
TSS discharge (Tons)	8.68	17.53
COD concentration (mg/l)	310.99	85.92
TSS concentration (mg/l)	145.78	78.15
Age (Decades)	2.29	1.31
Inspection (Times)	2.19	1.52
Citizen's Complaint (Times)	0.07	0.27
Adapt to Low Rate	62%	
Adapt to High Rate	38%	
Food	37%	
Chemical	39%	
Paper	15%	
Medicine	9%	
State owned	25%	
Collective	45%	
Joint Venture	30%	
Number of plants	137	
Number of observations	548	

5 Models and results

In this section, we provide the models and regression results in three steps. First, we discuss ordinary least squares estimates of the basic model to examine the impact of inspections and then we check the possible biases of simple OLS estimations. Second, we modify our estimations by using two stage least-squared method with a instrument variable. Finally, we compare our results with the ones from previous studies.

5.1 The basic model

We first present a simple regression model by using ordinary least-square (OLS) estimations. The objective here is to test for the impact of inspections on two sets of variables: (i) the *absolute* discharge of COD and TSS and (ii) the level of discharges of COD and TSS *relative* to their respective standards (namely, the discharges exceeding the corresponding concentration standards). The model estimated is of the same form regardless of emission variables of interest. The equations estimated are of the form:

$$Z_{i,t} = c + \beta_1 INS_{i,t} + \beta_2 INS_{i,t-1} + \beta_3 OPT_{i,t} + \beta_4 AGE_i + \beta_5 EMP_i + \beta_6 RATE_i + \gamma SEC_i + \delta OWN_i + \varepsilon_{i,t}$$

where $Z_{i,t}$ denotes the emission variables (it is *self-reported* emissions as we argue before) associated with plant i at time t[10]; $INS_{i,t}$ stands for inspections performed at plant i at time t; $INS_{i,t-1}$ correspondingly represents inspections at time $t-1$; $OPT_{i,t}$ is plant i's value of output at period t; AGE_i gives the age (in terms of number of years) of plant i; EMP_i is the number of employees of plant i; $RATE_i$ is a tax rate dummy that takes value 1 if plant i pays levies for their COD emissions according to the cheaper rate R_1; SEC_i is a matrix of dummies to indicate a plant's industrial sector of activity, including food, chemical and medicine; OWN_i is also a matrix of dummies to represent a plant's ownership. Finally, $\varepsilon_{i,t}$ is the usual error term.

Our empirical model is different from our theoretical model in the sense that we allow plants to be different in their production efficiency (with respect to emissions) in our empirical analyses. In the theoretical model, we analyze behavior of a plant under imperfect enforcement, and hence we consider that the plant's production efficiency (revenue function $g(\cdot)$ with respect to actual emissions) are exogenously given. However, in empirical aspect, since we have 137 plants in our data set, we need to take into account the fact that plants are different in their production efficiency, and the plants' value of output is the proxy variable to catch the difference. Moreover, our model should also take into account the fact that the independent variables (plant's

[10] In some specifications, $E_{i,t}$ is the absolute discharges, while in others, it is discharges in excess of the standards. $E_{i,t}$ may be negative when it represents the plants' relative TSS discharges and they are up to standards.

reported emissions) can also be partly explained by their actual emissions that vary with the levels of output. Given that plants' actual emissions are not observable, the variable value of output again is a good measure of the variation of a plant's actual emissions across quarters due to its different amounts of production. Therefore, our empirical model is also different from the theoretical model in the sense that here we consider that plants' reported emissions are the function of plants' actual emissions for which plants' value of output are proxy. In the theoretical model, both the plants' difference of production efficiency and the variation of a plant's actual emissions due to different amounts of production are simply represented by a given revenue function.

The model is different from the traditional empirical analyses of this context. The variable value of output in our model takes the same role as lagged independent variables in those previous studies[11]. Under the assumption that there are not drastic changes in production and in the pollution abatement technology during the year 2002, value of output makes a better proxy for actual pollutions emitted by a plant and also explains the plants' scale effects (different production efficiency). As we have already pointed out, emission variable in our data set is self-reported, not actual pollution, hence using lagged independent variables as regressors may cause systematical bias. We also use number of employees, plant's age, sector and ownership as regressors. Wang and Wheeler (2005) find that those variables significantly explain plants' performance in pollution.

The results from the estimations are presented in Table II. There are four sets of results corresponding to the two measures of two kinds of pollution emissions. Note first that as expected, the coefficients on value of output are positive and have strong positive influence on pollution discharges, except on the relative TSS discharge. Besides the output value, other factors, such as sector dummies and ownership dummies, also report significant effects on pollution discharges. The coefficients of sector dummies have very strong

[11] LR uses 12-period lagged pollution and DL uses one period lagged pollution. In fact, they acknowledge in their papers that it may be better to use production as a regressor in the model but it was not available in their analysis.

negative effects on COD discharges, while they report weaker and ambiguous effects on TSS discharges (negative on absolute TSS discharges but positive on the relative ones). The reason is medicine manufacturing plants pollute more COD than plants with other sectors. Moreover, plants with medicine sector are comparative large polluters in absolute TSS discharges but not in relative TSS discharges, which is the reason why the coefficients of sector dummies are ambiguous with respect to TSS discharges. Hence, it is not necessary that emissions by large polluters deviate more from the standards than emissions by small polluters. State-owned and collective enterprises appear to exacerbate pollution, which is in accordance with the fact that they have lower producing efficiency than plants with joint venture ownership and the fact that state-owned plants have much more bargaining power with environmental authorities in enforcement of pollution charges (see also DL and Wang et. al. 2002).

The coefficients estimate on current inspections in the results of COD discharges are positive and significant, while they have no significant effects on TSS discharges. It might be the reason that inspections mainly target on the pollutant for which plants pay their pollution levies. It also might be the reason that plants react inspections by only paying attentions to the pollutant that they pay pollution taxes for. Current inspections increase plants' self-reported absolute and relative COD pollution by 3.7% and 3.16%, while one period lagged inspections show no significant effect. These results provide strong evidence that plants underreport their emissions and hence confirm our conjecture that emission variables in the data set are just plants' self reported emissions but not their actual emissions. The results also show us that inspections are effective mainly on verifying plants' reported emissions instead of providing active deterrence for plants' pollution control.

Table II Emission Equations by OLS

(Sample Size:411)

Independent Variable	COD Discharges Absolute	COD Discharges Relative	TSS Discharges Absolute	TSS Discharges Relative
INT_t	2.0532**	1.0974*	0.5694	0.0155
	(0.9367)	(0.6705)	(0.3969)	(0.3599)
INT_{t-1}	-0.3612	-0.6399	0.6364	0.6081
	(1.0314)	(0.7383)	(0.4370)	(0.3962)
OPT_t	6.8907***	4.0358***	2.0990***	0.1284
	(0.2758)	(0.1974)	(0.1169)	(0.1060)
AGE	1.1226	1.1829	-0.0905	-0.4049
	(1.3655)	(0.9774)	(0.5785)	(0.5246)
EMP	-0.0002	0.0032	-0.0056**	-0.0035
	(0.0062)	(0.0045)	(0.0026)	(0.0024)
Rate	-6.3792**	-3.2934	-0.2427	1.7097
	(3.1447)	(2.2512)	1.3325	(1.2082)
Food	-37.9595***	-26.8113***	-5.7401***	2.5821
	(4.6471)	(3.3267)	(1.9691)	(1.7857)
Paper	-34.4710***	-27.8507***	-2.2440	3.6405*
	(5.0219)	(3.5949)	(2.2179)	(1.9293)
Chemical	-28.9541***	-19.8509***	-3.2032*	3.4754**
	(4.2442)	(3.0383)	(1.7984)	(1.6306)
State-owned	14.7699***	6.7475**	7.1409***	2.5958*
	(3.9503)	(2.8278)	(1.6738)	(1.5176)
Collective	9.7196***	5.9849***	2.5566*	0.0475
	(3.1824)	(2.2781)	(1.3485)	(1.2226)
Constant	14.6644**	12.0357***	0.2173	-2.0758
	(5.7726)	(4.1324)	(2.4460)	(2.2178)
R^2	0.8224	0.7682	0.6924	0.0508

In our panel data set, the number of observations (4) for each plant is much less than the number of plants (137). Hence, one question that naturally arises here is whether the estimated coefficients on inspections do explain how *a plant* reacts to inspections imposed on it. In other words, the coefficients of inspections in above regressions might be biased. For instance, if large polluters are inspected more frequently than small ones, the positive coefficients of inspections might just explain that large polluters report more pollution than small ones, and hence the inspection variable is just a proxy for large and small polluters (*inter-plant effects*). Again, we expect the coefficients of inspections estimate how a plant's reported emissions react to inspections (*intra-plant effects*). In order to test whether the coefficients of inspections catch the inter-plant effects or intra-plant effects, we run a simple OLS regression in which we average all quarterly variables with respect to 137 plants. The results are presented in Appendix II. The plants' average numbers of inspections are shown no significant influence on plants' average COD discharges. Therefore, we can conclude that the coefficients on the current inspections in Table II mainly estimate the *intra-plant effects.*

Another concern in the context of this study is the possible endogeneity of inspections and its effect on the least-squares estimates. If inspections are endogenous and correlated with the same variables that determine current pollution levels, then the OLS estimations will be biased in general. Put it in another way, inspections by environmental agencies themselves may be somehow triggered by plants' pollution levels. Given this potential problem, it is sensible to test for the exogeneity of current inspections. The Wald test on the basic model strongly rejects the hypothesis of exogeneity (Wald's statistics: 45.32).

5.2 Endogenous inspections

In order to fix this problem, we may look for another variable (instrument variable) to model inspections that does not enter in the basic model. A good instrument is the variable that affect dependent variable only through the endogenous variable. Citizens' complaints appear as a good candidate for instrument variable. The fact is that citizens' complaints are directly made to environmental authorities not to plants, and hence citizens' complaints may influence plants' reported emissions but only through inspections conducted by environmental authorities. We run a simple regression in which we put both inspections and citizens' complaints as regressors. The results are shown in the Appendix III. Citizens' complaints turn out to have no significant direct impact on plants' reported emissions. On the other hand, citizens' complaints are positively correlated with inspections (correlation coefficient: 0.3174). Hence, we can build up a model that involves simultaneously both the inspections equation and the pollution equation with citizens' complaints' appearing in the former but not in the latter. The model is the following:

$$\begin{aligned} INS_{i,t} &= c + \alpha_1 CMP_{i,t} + \alpha_2 INS_{i,t-1} + \alpha_3 OPT_{i,t} + \alpha_4 AGE_i \\ &\quad + \alpha_5 EMP_i + \alpha_6 RATE_i + \mu SEC_i + \theta OWN_i + \sigma_{i,t} \\ Z_{i,t} &= c + \beta_1 INS_{i,t} + \beta_2 INS_{i,t-1} + \beta_3 OPT_{i,t} + \beta_4 AGE_i \\ &\quad + \beta_5 EMP_i + \beta_6 RATE_i + \gamma SEC_i + \delta OWN_i + \varepsilon_{i,t} \end{aligned}$$

where $CMP_{i,t}$ denotes the number of citizens' complaints against plant i at period t. $Z_{i,t}$ here only refer to plants' COD discharges but not their TSS discharges because there are no significant impacts of inspections on TSS discharges as we show in OLS estimations.

We use two stages least-squared (2SLS) estimations. We also relax the usual assumption on estimation residuals ($\sigma_{i,t}$ and $\varepsilon_{i,t}$) by using cluster robust on plants[12]. The results of the first stage (Inspection Equation) are reported in the Table III, while the results of the second stage (Emission Equations) can be found in Table IV.

[12]Estimation residuals are ususally assumed to be identically and independently distributed (IID). However, in our model the IID assumption is too strong, we hence relax the assumption by allowing the distributions of residuals not to be necessarily identical with different plants (cluster robust with plants).

Table III Inspection Equation (First Stage)[♯]
(Sample Size: 411)

Independent Variable	INT_t
Complaint	1.6014***
	0.0512
INT_{t-1}	0.1832***
	(0.0512)
OPT_t	0.0433***
	(0.0135)
AGE	0.2090***
	(0.0667)
EMP	0.0001
	(0.0003)
Rate	0.4837***
	(0.1537)
Food	-0.9097***
	(0.2253)
Paper	-0.8997***
	(0.2448)
Chemical	-0.5119**
	(0.2086)
State-owned	0.0319
	(0.1954)
Collective	0.0075
	(0.1573)
Constant	1.3551***
	(0.2774)
R^2	0.4929

[♯]Standard errors by cluster robust with plants.

The regression results of inspections equation tell us the inspection strategies of the environmental agency (FEPB). First, larger polluters are more likely to be inspected than smaller polluters. It can be supported by the following observations: the coefficient estimates on output value is positive and strongly significant; the plants with medicine sector attract many more inspections than other plants; inspections on state-owned plants (usually large polluters) are more frequent than on plants with other ownerships. Second, one-period lagged inspections indicate a significantly persistent effect on current inspections. Third, older plants are more likely to be inspected. Finally, citizens' complaints have a strong effect on inspections, which is confirmed by our conversations with FEPB's employees: inspections are also triggered by citizens complaints.

As for the emissions equation, the results are similar to those obtained in the basic model. However, now current inspections appear as having a more impact on plants' reported emissions. Current inspections increase plants' reported absolute and relative COD discharges by 8.26% and 7.91%.

Table IV Emissions Equations (Second Stage)♯

(Sample Size:411)

Independent Variable	COD Discharges Absolute	COD Discharges Relative
INT_t	4.5900**	2.7488*
	(2.0753)	(1.4348)
INT_{t-1}	-0.6754	-0.8445
	(1.5340)	(1.0935)
OPT_t	6.7861***	3.9677***
	(0.9446)	(0.7706)
AGE	0.5318	0.7983
	(2.1010)	(1.4610)
EMP	-0.0009	0.0028
	(0.0129)	(0.0102)
Rate	-7.6504	-4.1209
	(4.9778)	(3.2953)
Food	-35.4238**	-25.1604**
	(14.0931)	(10.3594)
Paper	-32.2003**	-26.3727***
	(12.4133)	(9.969)
Chemical	-27.7196**	-19.0473**
	(13.1287)	(9.6395)
State-owned	14.5182**	6.5836
	(6.7465)	(5.1723)
Collective	9.6919*	5.9669*
	(5.3236)	(3.5315)
Constant	10.9002	9.5854
	(16.5708)	(12.2995)
R^2	0.8191	0.7647

♯Standard errors by cluster robust with plants.

5.3 Comparison with the previous studies

In this part, we argue how and why our results are different from the previous studies in this context. Our regression results are sharply different from those of MV and LR in studies of American and Canadian cases. In MV and RL, inspections are shown to reduce plants' self reported pollution by 20% and 28% while inspections increase plants' self reported emission by 8.26%. Therefore, in China plants underreport their emissions but in US/Canada plants seemly report their emissions truthfully. The drastic difference can be explained by the different institutional arrangement between China and US/Canada in environmental regulations and enforcement.

First, China's environmental regulations are mainly based on pollution taxation, while the US and Canada mainly use standards to control pollution. With taxation, the target of inspections is to make plants pay taxes according to their actual emissions, but with standards, inspections aim at inducing plants emit their emissions below standards. The different regulations lead to the different purposes of inspections. Hence with taxes inspections mainly make plants report truthfully, while with standards inspections reduce plants actual emissions and therefore reduce their reported emissions.

Second, in China plants usually only face a limited monetary penalty for underreporting their emissions, which is unlike the American and Canadian cases where fraud in reporting is a serious criminal offense. As we mentioned before the limited monetary penalty make plants able to fix the possible cost of noncompliance in China. However, in US/Canada, plants prefer to report truthfully even if they do not comply with the standards, because the penalty for noncompliance is much less than fraud reporting.

Third, in China plants are required to make ex-ante self reports, while in US/Canada plants' self reports are ex post. The China's specific procedures give plants incentives to report their emissions strategically. For instance, plants can just predict less emissions in their reports at the beginning of a year and then decide whether to modify their initial reports depending on how many inspections are imposed on them.

Finally, inspections made by China's environmental authorities seemingly just verify plants' reported emissions, while inspections conducted by US/Canada environmental agencies provide marginal deterrence on plants' noncompliance with standards. For instance, in our data the quarterly average times of inspections are 2.19 per plant. However, in MV and LR the corresponding numbers are 0.044 and 0.128 respectively. Moreover, one period lagged inspections show no significant effect on plants' self reports but in MV and LR the past inspections have strong influence on plants' current state of compliance. We can also find evidence from environmental agencies' inspection strategies: one-period lagged inspections indicate a significantly persistent effect on current inspections in our case, while the probability of an current inspection is a decreasing function of past inspections in LR. It implies that environmental agencies in China target on verification but environmental authorities in Canada maximize marginal deterrence.

Based on these concerns, we consider plants' self reported emissions just as they are, while MV and LR treated plants' self-reported emissions as their actual emissions. Hence, we explain our regression results as that inspections increase plants' reported emissions by 8.26%, but MV and LR conclude that inspections reduce plants actual emissions by 20% and 28%.

Our results are also different from those of DL, even if both use China's data. According to DL's results, current year's inspections reduce plant's reported emissions by a very little amount (0.40% on COD). The possible reasons of this difference are following. Note first that, their data are annual based while ours are quarterly. Since field inspections have strong instant time effects, an inspection that happened a year ago may not influence plant's current decisions at all. Second, the data set in DL also includes plants that do not pay levies (57% of total plants). Since plants only pay levies for one of their pollutants, there are even less sample plants pay levies on their COD or TSS emissions that DL use as dependent variables. Finally, in DL the dependent variable (COD or TSS) is measured only as the level of discharge relative to their respective standards but not as the commonly used absolute emissions.

6 Conclusion

We have discussed China's environmental regulations in detail and analyzed plants' behavior when they do not perfectly comply with the specific environmental levy system. In our theoretical analysis, we have concluded that plants' actual pollution firstly decreases and then jumps to a higher level as the audit probability (number of inspections) increases, but plants' self-reporting pollution is a monotonically increasing function of audit probabilities. Furthermore, the gap between plants' actual and self-reported pollution always narrows with the increase of enforcement.

In our empirical estimations, we have adopted a unique data set collected from FEPB, China, in which we only integrate plants who pay environmental taxes on a specific pollutant (COD). By acknowledging the fact that plants' real pollution is unobservable, we simply treat plants' pollution in our data as their self-reported pollution. We have provided clear empirical evidence that inspections conducted by environmental agencies significantly and positively increase plants' reported absolute and relative COD emissions by 8.26% and 7.91%. Hence, we find strong evidence that plants underreport their pollution. The results are compatible with our theoretical results.

Our results are in contrast with similar studies in US and Canada cases. The institutional aspects of China's environmental regulations explain well this difference. In particulars, US and Canada implement emission standards while China uses emission taxation. Moreover, the limited monetary penalties for fraud reporting and the specific procedures of self reporting in China fail to provide plants a strong incentive to report their emissions truthfully. Our results are also different from the similar previous studies about China. The main reason is that we sample our data by only integrating plants paying environmental levies.

Our study has provided key policy implications. Particularly, the impact of enforcement actions on polluters' environmental performance heavily depends on environmental regulations themselves. China's regulations make environmental enforcement actions effective mainly on verifying plants' reported pollution but not on reducing plants' actual pollution. In order to control pollution, a reform of the regulations is necessary.

7 Appendix I

Proof of Proposition 2. We start by providing two lemmas based on Proposition 1. The first Lemma describes the marginal effect of tax rates on expected profits for a given audit probability; the second Lemma shows that this effect is nonincreasing in audit probabilities. ■

Lemma 4 *When a plant faces a unique tax rate R, its expected profits $E\pi$ are nonincreasing in R for any given $\rho \in [0,1]$, in particular:*

$$\frac{\partial E\pi}{\partial R} = 0 \textit{ if } \rho < \frac{R}{\theta'(E^*)}; \frac{\partial E\pi}{\partial R} < 0 \textit{ otherwise.}$$

Proof. If $\rho < \frac{R}{\theta'(E^*)}$, the plant emits E° according to (1) and reports $Z^o = 0$. Since $g'(E^\circ) - \rho\theta'(E^\circ)$ is independent on the tax rate R, we get $\frac{\partial E\pi}{\partial R} = 0$ immediately. If $\rho \geq \frac{R}{\theta'(0)}$, the plant emits and reports E^* and the plant's profit are $g(E^*) - E^*R$. We have $g(E^*) - E^*R < g(E^*) - E^*R' \leq g(E^{*\prime}) - E^{*\prime}R'$, where $R' < R$ and $g'(E^{*\prime}) = R'$, so we show $\frac{\partial E\pi}{\partial R} < 0$. If $\frac{R}{\theta'(E^*)} \leq \rho < \frac{R}{\theta'(0)}$, by the envelop theorem (E and Z are interior solutions in this region), we have $\frac{\partial E\pi}{\partial R} = -Z < 0$. ■

Lemma 5 *When a plant faces a unique tax rate R, the $\frac{\partial E\pi}{\partial R}$ is nonincreasing in ρ, in particular:*

$$\frac{\partial^2 E\pi}{\partial R \partial\rho} = 0 \textit{ if } \rho < \frac{R}{\theta'(E^*)} \textit{ or } \rho \geq \frac{R}{\theta'(0)}; \frac{\partial^2 E\pi}{\partial R\partial\rho} < 0 \textit{ otherwise.}$$

Proof. The first part is immediate after Lemma 4 . Moreover, if $\frac{R}{\theta'(E^*)} \leq \rho < \frac{R}{\theta'(0)}$, again by the envelop theorem, we have $\frac{\partial^2 E\pi}{\partial R\partial\rho} = -\frac{\partial z}{\partial\rho} < 0$.

We now address the proof of Proposition 2.

For a given ρ, define $E\pi_1 = \arg\max_{E,Z} g(E) - ZR_1 - \rho\theta(E - Z)$ and correspondingly $E\pi_2 = \arg\max_{E,Z} g(E) - ZR_2 - \rho\theta(E - Z)$. We also define $\Delta E\pi = E\pi_1 - E\pi_2$. From Lemmas 4 and 5, we know that $\Delta E\pi$ is nonnegative

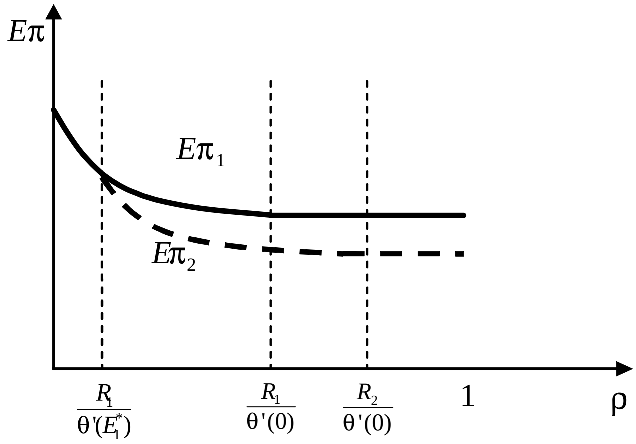

Figure 3: Expected profits under R_1 and R_2

and nondecreasing on ρ. Figure 3 describes $E\pi_1$ and $E\pi_2$ (according to Proposition 1), where the vertical ax represents plant's expected payoff and the horizontal ax denotes the audit probability.

If $\rho \leq \frac{R_1}{\theta'(E_1^*)}$, $E\pi$ is independent of the tax rates so $E\pi_1$ and $E\pi_2$ coincide; otherwise, $E\pi_1$ (bold line) is above $E\pi_2$ (dashed line). Based on Lemma 5, $\Delta E\pi$ is independent of the audit probabilities not only when $\rho < \frac{R_1}{\theta'(E_1^*)}$ but also when $\rho > \frac{R_2}{\theta'(0)}$ (true report), and $\Delta E\pi$ is increasing on audit probability otherwise. The maximum value of $\Delta E\pi$ is obtained when $\rho = \frac{R_2}{\theta'(0)}$ and it is given by $g(E_1^*) - E_1^* R_1 - [g(E_2^*) - E_2^* R_2]$, that we denote by $\overline{\Delta E\pi}$.

We first consider type 1 plants with $E_1^* \leq T$. In those cases where reporting a positive emission is optimal, adapting the tax rate R_1 requires the plant to report an emission higher than T. Obviously, the plant would need to over report its emission, so adapting R_1 is not optimal. For the second case in Type 1 plants, $g(E_2^*) - R_2 E_2^* \geq g(E_1^*) - R_1 E_1^* - L_0$, that is, $\overline{\Delta E\pi} \leq L_0$, Hence, adapting to R_1 is also not optimal.

On the other hand, if $g(E_2^*) - R_2 E_2^* < g(E_1^*) - R_1 E_1^* - L_0$, we have $\overline{\Delta E\pi} > L_0$. $\Delta E\pi(\rho)$ is increasing on ρ in the interval $[\frac{R_1}{\theta'(E_1^*)}, \frac{R_1}{\theta'(0)}]$. As a result, there exists a critical auditing probability $\rho^* \in (\frac{R_1}{\theta'(E_1^*)}, \frac{R_1}{\theta'(0)})$, such that $\Delta E\pi(\rho) = L_0$. ρ^* is defined by $-R_1 + \rho^* \theta'(E_1^* - T) = 0$ (That comes from at ρ^*, FOC with respect to reported emission is binding according to

R_1). For $\rho < \rho^*$ the plant makes decisions according to R_2; for $\rho \geq \rho^*$, plants make decisions according to R_1.

Finally, if $T < E_2^*$ adapting to the tax rate R_2 is not optimal under perfect compliance. A plant first adapts to R_2 and then to R_1 depending on the critical auditing probability ρ^* as defined in the previous paragraph. ■

Proof of Corollary 3. Results in (1) are immediately after Proposition 2. For the (2), considering firstly the case $\rho^* \leq \frac{R_2}{\theta'(E_2^*)}$, before jumping (adapt to R_2) the gap E_2° defined by $g'(E_2^\circ) - \rho^*\theta'(E_2^\circ) = 0$, and after jumping (adapt to R_1) the gap $E_1^* - T$ defined by $-R_1 + \rho^*\theta'(E_1^* - T) = 0$. Therefore we have $\frac{\theta'(E_2^\circ)}{\theta'(E_1^* - T)} = \frac{g'(E_2^\circ)}{R_1}$. By $\frac{R_1}{\theta'(E_1^*)} < \rho^*$, we have $g'(E_2^\circ) > g'(E_1^*) = R_1$ and the convexity of θ function, so we conclude $E_2^\circ > E_1^* - T$. For the case where $\rho^* > \frac{R_2}{\theta'(E_2^*)}$, before jumping (adapt to R_2) the gap $E_2^* - Z_2^\circ$ defined by $-R_2 + \rho^*\theta'(E_2^* - Z_2^\circ) = 0$, and after jumping (adapt to R_1) the gap $E_1^* - T$ defined as before. Therefore we have $\frac{\theta'(E_2^* - Z_2^\circ)}{\theta'(E_1^* - T)} = \frac{R_2}{R_1}$, since $R_2 > R_1$, we can easily conclude that $E_2^* - Z_2^\circ > E_1^* - T$. ■

8 Appendix II

Table V: Inter- or Intra- plants effects (Sample size: 137)

Independent Variable	Average COD Discharges	
	Absolute	Relative
Average INT_t	2.0816	0.2722
	(2.9209)	(2.0968)
Average OPT_t	6.9003***	4.0729***
	(0.4946)	(0.3551)
AGE	1.0743	1.2654
	(2.4641)	(1.7689)
EMP	-0.0010	0.0028
	(0.0111)	(0.0080)
Rate	-6.6513	-3.2481
	(5.6359)	(4.0458)
Food	-37.4749***	-26.9390***
	(8.4423)	(6.0603)
Paper	-34.0759***	-27.9485***
	(9.0473)	(6.5090)
Chemical	-28.5390***	-19.7829***
	(7.5603)	(5.4272)
State-owned	14.8131**	6.9699
	(6.9973)	(5.0231)
Collective	9.7433*	6.0200
	(5.6350)	(4.0451)
Constant	14.1364	12.3332
	(10.5967)	(7.6069)
R^2	0.8224	0.7681

9 Appendix III

Table VI Emissions Equations OLS with Complaint (Sample Size:411)

Independent	COD Discharges	
Variable	Absolute	Relative
Complaint	4.7478	3.0906
	(4.2267)	(3.0552)
INT_t	1.6252	0.8188
	(1.0124)	(0.7249)
INT_{t-1}	-0.1321	-0.4908
	(1.0514)	(0.7529)
OPT_t	6.9147***	4.0513***
	(0.2766)	(0.1980)
AGE	1.1516	1.2017
	(1.3652)	(0.9776)
EMP	-0.0007	0.0029
	(0.0063)	(0.0045)
Rate	-6.2163**	-3.1873
	(3.1472)	(2.2536)
Food	-38.1208***	-26.9163***
	(4.6480)	(3.3282)
Paper	-34.8677***	-28.1090***
	(5.0330)	(3.6039)
Chemical	-29.2371***	-20.0351**
	(4.2506)	(3.0437)
State-owned	14.6128***	6.6452**
	(3.9516)	(2.8296)
Collective	9.7142***	5.9814***
	(3.1814)	(2.2781)
Constant	14.9177***	12.2005***
	(5.7753)	(4.1355)
R^2	0.8229	0.7688

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