Enforcement of Environmental Regulation in China

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Contents

Chapter 1

Introduction

There is now a vast literature on both theoretical and empirical studies on the monitoring and enforcement of environmental regulations. Most of these studies, especially those empirical researches, have targeted on understanding the deterrence effect of environmental monitoring and enforcement in North America. Given the dominance of pollution standard regulations in the US and Canada, the literature has generally focused on the determinants of compliance with pollution standards. However, different from the pollution standard regulations in North America, a pollution fee/tax (so called pollution levy) system has been imposed on firms' pollution in China. The different regulations in US/Canada and China bring the different contents of environmental monitoring and enforcement. In this thesis, we investigate both environmental regulators' enforcement and firms' compliance behaviors under China's specific pollution levy system.

The discussion of a possible pollution regulatory system began in China after the United Nations Stockholm Conference on the Human Environment in 1972. The idea was formally adopted by the central government in 1978. Article 18 of the "Trial Environmental Protection Law", which was issued in 1978 and enacted in 1979, 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". Several local governments immediately began experimenting with charges, and by the end of 1981, 27 of China's 29 provinces, autonomous regions and municipalities had established the pollution levy system. Local governments in China have extensive flexibility in both formulating and enforcing environmental regulations.

Under the pollution levy system, all polluters are required to self-report their pollution to environmental authorities. The detailed procedures of implementing the levy system are as follows. At the beginning of a year, plants make ex ante reports on their pollution in the coming year. 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/month, based on plants' reports and inspections (authorities' verification), authorities notify the amount of discharge pollution (verified pollution) and the levies they should pay in this month/quarter. In case of false reporting (firms' self-reports deviate from authorities' verification by a large margin), plants are liable to penalties.

Given the pollution levy system, a few questions are of interest. For instance, whether firms intend to evade pollution levies by underreporting their pollution; how polluters react to environmental authorities' inspections under China's pollution taxation; what is the process leading the regulators to undertake enforcement activities and how effective environmental regulations depend on firms' local conditions; whether firms strategically report their pollution under the specific ex-ante self-reporting procedure.

In the second chapter of this thesis, 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 & Viscusi, 1990; Laplant & 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.

In the third chapter of this thesis, we investigate the effect of firms' local conditions on their effective environmental regulation in China, from both a theoretical and empirical points of view. We show that environmental agencies take into account firms' age and ownership when they impose plants' pollution standards and undertake inspections. We also show that plants who are located in higher GDP per capita areas and whose emissions are more likely to induce pollution damages are facing stricter effective environmental regulation, that is stricter pollution standards and more frequent inspections.

Our results offer important insights into the regulator's behavior: environmental agencies do take public interests in plants' pollution into account when they determine plants' regulation. Plant's effective environmental regulation is strongly influenced by the local costs and benefits of plants' pollution, which is consistent with the principle of environmental economics, that is, environmental regulation is the outcome of balancing the economic activity and environmental degradation due to the pollution by taking all benefits and costs into account.

In the fourth and last chapter of this thesis, we analyze whether and how firms strategically report their pollution under the specific ex ante self-reporting procedure. We estimate that each inspection (fine) increases the firms' likelihood of modification by 19.62% (64.3%). Moreover, each inspection (fine) increases the firms' likelihood of increasing reports by 22.49% (28.85%). The study, together with the second chapter, provides clear evidence that firms significantly underreport their pollution and enforcement actions by environmental agencies are mainly effective in inducing firms to report their pollution more accurately.

Each chapter is self-contained and, therefore, can be read independently.

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Chapter 2

Enforcement of Pollution Taxation in China

2.1 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,

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[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.

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 & 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 literatures on these issues[2].

Magat & Viscusi (1990) (henceforth MV) and Laplante & 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 & 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 exam-

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

ined 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 & 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 by Macho-Stadler & 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 2.2, we present China's environmental regulations in detail. In Section 2.3, a model analysis, integrating China's specific environmental regulations, is provided. In Section 2.4, we present and describe our data set. In Section 2.5, empirical models and results are presented. Section 2.6 concludes. Theoretical proof can be found in Appendix I.

2.2 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*.

2.2.1 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 exceeded its standard by the greatest

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

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 respect to those pollutants emitted by plants above their corresponding standards. Now, consider a plant j emitting M water correlated pollutants that are above the corresponding 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 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

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[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. $USD\$1 \approx RMB¥7.5$

[5] The formula is calculated on monthly base.

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 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

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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.

[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.

with the principles of environmental economics, since the more pollutants a plant emit, the cheaper the levy rate the plant is subject to.

2.2.2 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 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.

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[8] It varies with regions.

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.

2.3 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: environmental 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.

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[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.

2.3.1 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 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 written as:

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

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:

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

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

2.3.2 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 $Z^\circ = 0$:

$$g'(E^\circ) - \rho\theta'(E^\circ) = 0. \tag{2.3.1}$$

(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.

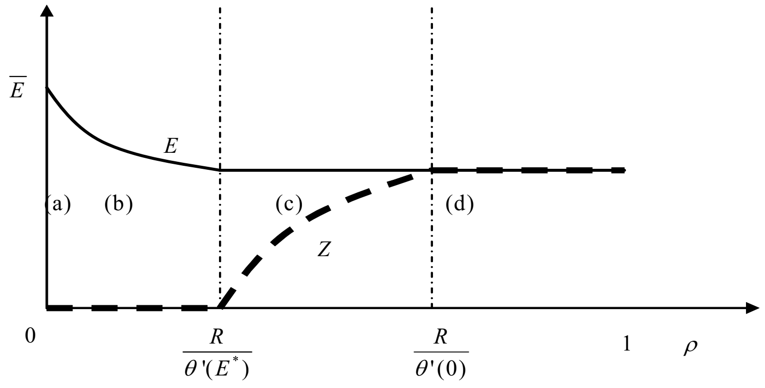

Figure 1: Emission and report with a linear tax

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 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 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.

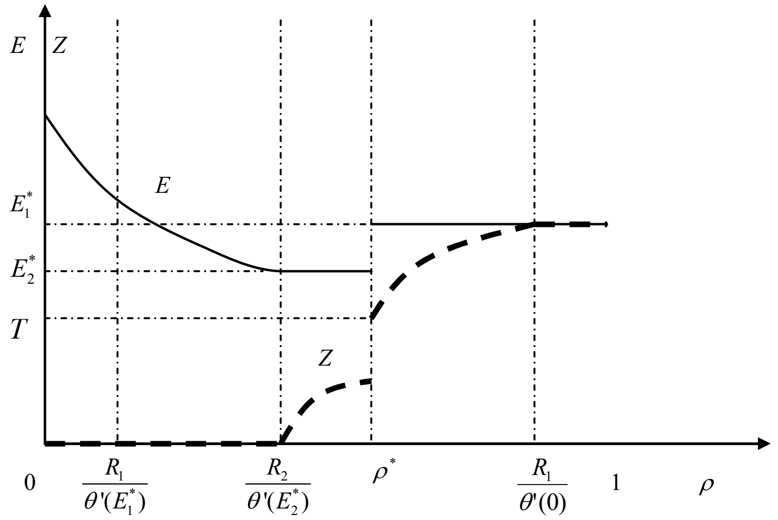

Figure 2: Emissions and report under China's system in region 2

Corollary 1 *(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.

2.4 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 & 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 & 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 or verified self-report emissions, which are based on plants' self reports and verifications by environmental agencies. 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	

2.5 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.

2.5.1 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:

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

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 reported emissions) can also be

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

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 & 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 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

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[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.

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).

Table II Emission Equations by OLS (Sample Size:411)

Independent Variable	COD Discharges		TSS Discharges	
	Absolute	Relative	Absolute	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

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.

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.

2.5.2 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:

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

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. Before we explain the regression results, we first run the test for the exogeneity of current inspections. In the

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[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).

two stage regression with the instrument variable citizens' complaints, the Wald test of strongly rejects the hypothesis of exogeneity (Wald's statistics: 45.32).

Table III Inspection Equation

(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

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.

Table IV Emissions Equations

(Sample Size:411)

Independent Variable	COD Discharges	
	Absolute	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

Cluster robust with plants

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%.

2.5.3 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.

2.6 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.

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2.7 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 1 *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:*

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

Proof. If $\rho < \frac{R}{\theta'(E^*)}$, the plant emits E° according to (2.3.1) 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 2 *When a plant faces a unique tax rate R, the $\frac{\partial E\pi}{\partial R}$ is nonincreasing in ρ, in particular:*

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

Proof. The first part is immediate after Lemma 1 . 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 1 and 2, we know that $\Delta E\pi$ is nonnegative 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.

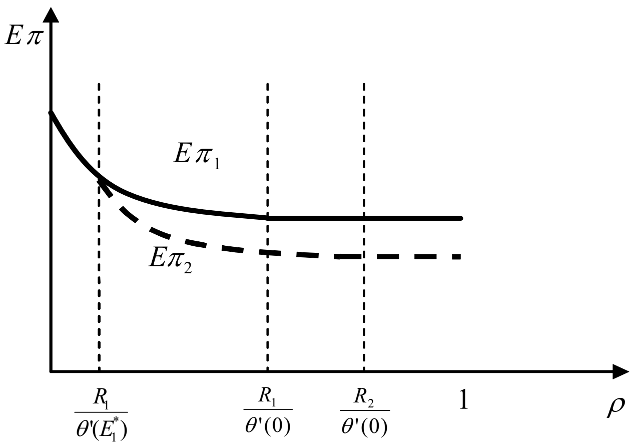

Figure 3: Expected profits under R_1 and R_2

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 2, $\Delta E\pi$ 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 $E_2^* - Z_2^\circ > E_1^* - T$. ■

2.8 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

2.9 Appendix III

Table VI Emissions Equations with Complaint

(Sample Size:411)

Independent Variable	COD Discharges 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

Cluster robust with plants

Chapter 3

Local Variations of Effective Environmental Regulation: Evidence from China

3.1 Introduction

Environmental regulations in China can be traced back to 1979 when the national Environmental Protection Law (EPL) was adopted (on a trial basis). Following the EPL, a series of environmental regulations have been designed to reduce industrial pollution and improve environmental quality. Although the pollution control regulation has been amended several times, it always mainly involves a pollution tax charge that is called pollution levy system.

Environmental management in China is generally decentralized. Article 16 of Chapter 3 of the EPL indeed states that "the local peoples' governments at various levels shall be responsible for the environmental quality of areas under their jurisdiction and shall take measures to improve the quality of the environment." Therefore, local governments have extensive flexibility in both formulating and enforcing environmental regulations. For instance, local governments are involved in the decision concerning the pollution concentration standards for firms that emit to local waterways. Furthermore, the enforcement of environmental regulation (e.g., issuing firms' discharging license, making field inspections and collecting firms' pollution levies) is the responsibility of local environmental protection bureaus (EPB).[1] In addition, firms' pollution levies can be reduced or even eliminated at the discretion of local regulators after appropriate inspections.

Accompanying its fast economic growth, China's economy presents highly unbalanced regional development. A large disparity exists between the urban and rural areas and between the coastal and inland regions. Differences in per capita income, as well as in other parameters such as population density, firms' ownership, etc., may give rise to heterogeneous preferences concerning environmental quality. For example, high income areas, which have higher marginal willingness to pay for environmental quality, would typically like to impose stricter pollution regulations than those with a low income level. As a Chinese state EPA (Environmental Protection Agency) representative said, "Because some counties have very poor economic bases and are very concerned about improving their economies, environmental protection isn't important compared with developing the economy."[2] Different local incentives in environmental regulations may also arise due to financial incentives: if governments hold stakes in firms as it often happens in poor areas, they may not want those firms under strict environmental regulations. Moreover, environmental authorities may have less incentives to enforce regulations on those firms that are important employers in the local labor markets. Finally, other firms' local conditions also matter. For example, firms located in high population density areas may be imposed more strict pollution standards and more rigorous enforcement. The locally different incentives in environmental regulations, combined with local flexibility in formulating and enforcing environmental regulations, inevitably leads to regional diversity in firms' environmental performance.

Although the regional diversity in firms' environmental performance has been criticized,[3] recent research (see Wang & Wheeler, 2003) suggests that its pattern is consistent with one of the principles of environmental economics: in general, regulation is stricter in areas where income is higher.

The existence of variations in effective environmental regulations in China has been

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[1] The local EPBs are primarily an organ of local governments: the heads of the local bureaus are appointed by, and report to, the local governors; financial resources for the bureaus are also provided at the local level.

[2] People's news network, China, 2005.

[3] See, for instance, CRAES (1997).

pointed out by several papers. At the provincial level, Wang & Wheeler (2003) show that effective water levy rates are responsive to measures of ambient quality and development. Relatively affluent, heavily industrialized coastal provinces have the highest effective levy rates, while many poorer interior provinces have the minimum rates. More recently, Wang & Wheeler (2005) analyze financial incentives and endogenous enforcement in Chinese pollution levy system by using data from 3,000 Chinese factories and find that, despite central pressure for uniformity in enforcement, firms' compliance with environmental regulations reflects great local diversity.

Different from Wang & Wheeler (2003, 2005), in this paper we focus directly on analyzing the process leading the regulator to undertake enforcement activities and how effective environmental regulations depend on firms' local conditions.

The impact of increasing firms' pollution concentration standards on firms' environmental performance is unambiguous: higher (more permissive) standards lead to more pollution (See Cohen, 1999). As for how inspections influence firms' environmental performance, Dasgupta et al. (2001) conclude that, at the plant level, the variation in inspections is a better determinant of the Chinese polluters' environmental performance than the variation in pollution levies. Using quarterly data at firm's level, our analysis in Chapter 2 also concludes that inspections lead Chinese polluters to report their pollution more truthfully. Both studies show that inspections improve firms' environmental performance.

In the current paper, we first extend the model developed in Chapter 2 to show how the increase of firms' pollution concentration standards influences firms' actual and reported pollution. We then set up a simple bargaining game between central and local authorities to illustrate how the effective environmental regulations are determined. Finally, we empirically study the influence of local conditions on firms' pollution concentration standards and number of inspections subject to firms. We conclude that firms located in areas with higher GDP per capita are more likely to be imposed stricter pollution concentration standards and more inspection efforts. The plants located in urban areas and more populated counties are subject to stricter standards and enforcement. Moreover, firms with joint venture ownership are more likely to be regulated by more strict standards.

Most literature in this context has analyzed how firms' local conditions influence the enforcement activities in North America. For instance, Deily & Gray (1991) analyzed whether local labor market conditions affect the enforcement of pollution standards. In particular, they analyzed whether US EPA's enforcement actions depend on the probability that a plant closes as a result of these actions. Deily & Gray (1996) extended their previous study by introducing the economic theory of regulation to model the regulator's decision. More recently, Dion et al. (1998) studied the issue by using Canadian pulp and paper industrial firms' level data and they show that ceteris paribus, greater inspection effort is allocated toward those plants whose emissions are likely to generate a higher level of damages. They also show that variables pertaining to local labor market conditions have a significant impact on the monitoring strategy adopted by regulators.

The rest of this paper is organized as follows. Section 3.2 presents a model analysis on firms' compliance with environmental regulations and a simple bargaining game between local and central authorities on environmental regulations. Section 3.3 gives an empirical analysis. Section 3.4 concludes.

3.2 The Model

In this section, we first introduce the Chinese system of environmental levies. Then, we propose a theoretical model that includes the main ingredients of the system to analyze firms' behavior as a function of the enforcement policy. Finally, we introduce a simple bargaining model that includes the main factors of the negotiation that takes place between central and local authorities to determine the effective environmental regulations.

3.2.1 The Chinese Levy System

Since 1982, the Chinese pollution levy system has been amended several times in order to satisfy the rising social demand for ambient environmental quality. Given that our data set is based on plants' pollution in the year 2002, we mainly explain the pollution levy system at that time.

Chinese firms are subject to environmental levies as a function of the total wastewater discharge (or volume of air) and pollutant concentration. They are required to pay levies if their pollutant concentration exceeds the corresponding standard. More precisely, consider a particular water pollutant and a firm. Denote by W the total firm's wastewater discharge, C its pollutant concentration, and C^* the concentration standard. The discharge factor P is defined as $P = \max\left\{0, W\frac{C-C^*}{C^*}\right\}$. Then, the firm's levies for that pollutant are calculated as follows:

$$L = \begin{array}{ll} R_2P & \text{for } P \leq T \\ L_0 + R_1P & \text{for } P > T \end{array}$$

where R_1 and R_2 are tax rates with $R_2 > R_1$ and $L_0 = [R_2 - R_1]T$ is a fixed payment factor that makes the levy function continuous.

The wastewater levy system takes into account both the concentration of the hazardous pollutant and the volume of discharge wastewater, since it calculates the discharge factor (P) based on both total wastewater discharge and the degree to which pollutant concentration (C) exceeds the standard (C^*). The charge is zero when the pollutant concentration (C) is less than or equal to the standard (C^*). Both levy rates (R_1,R_2) and the threshold factor (T) are set by the central government and vary by pollutant, but not by industry or region. However, the concentration standard (C^*) is jointly set by the central and local governments, and it is different by industry and waterway where the wastewater is discharged. The central government sets three escalating classes of industrial pollution concentration standards (labeled as first, second and third class from strict to moderate) that vary by pollutant and by industry. The local environmental agencies pick up a proper class for those firms emitting pollutant to any local waterway.

The levy formula for each pollutant of air pollution is simpler:

$$L = \max\{0, RV(C - C^*)\}$$

where, R is the charge rate for this pollutant; V the total volume of air emission, C the pollutant concentration, C^* the corresponding concentration standard, and L the total levy. The determination of the policy for a particular firm follows steps similar to those described for wastewater pollution.

In the levy system, all polluters are required to register with their environmental agencies. Meanwhile discharging licenses are issued to the polluters by the environmental agencies. Firms are also required to self-report their emission and then pay the levy according to the levy calculation formula. The polluters' reports are checked by environmental regulation authorities in several ways, including internal consistency, consistency with material balance models, historical data from the facility and field inspections. Inspections mainly focus on verifying firms' self-reports.

3.2.2 The Model Analysis

A question which arises naturally here is how firms' pollution concentration standards and number of inspections affect firms' business outcome. Firstly, as pollution standards become stricter and inspections become more frequent, firms will invest more in abating pollution and therefore their profits will fall down. It is interesting for us to know how firms' pollution concentration standards and number of inspections affect their pollution decision and pollution levies. For this purpose, we conduct a brief theoretical analysis to explore firms' their environmental performance.

We build on the model originally introduced by Harford (1978) and extended by Macho-Stadler & Pérez-Castrillo (2006), and adopted to study the China's levy system in Chapter 2. In that chapter, we have shown that although more inspections introduce firms to report their pollution more truthfully to environmental agencies, they might also imply higher firms' actual pollution under the China's specific pollution regulation. Here we extended the analysis by focusing on how the increase of firms' pollution concentration standards influence firms' actual and reported pollution, and furthermore firms' profits.

We take firms' wastewater pollution as an example and assume that a firm only emits one kind of pollutant. In terms of pollution, a firm's decision has two dimensions: the volume (W) and the concentration (C) of the hazardous chemicals of wastewater. For a given pollution concentration standard and enforcement strength (inspections), the firm equalizes the marginal costs of abating the volume of wastewater and of decreasing the concentration of a specific pollutant. Therefore, for simplicity and without loss of generality, the firm's pollution concentration is assumed to be given, which is greater than the corresponding concentration standard (C^*).[4] Therefore, the firm's pollution can be measured only by the volume of wastewater. We denote $k = \frac{C-C^*}{C^*}$, which is a constant for a given concentration standard. The wastewater polluter decides how much

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[4] We consider the decision of firms whose (optimal) concentration is higher than the standard; otherwise, they are not subject to any levy.

to emit and how much to report. We denote by W the firm's real emission and by Z the self-reported emission level, so that the reported discharge factor is $P = Zk$. If a firm underreports its emission and if it is caught, then it has to pay a penalty. As in Chapter 2, we denote by $\theta([W - Z]k)$ the penalty the firm suffers (that also includes the evaded taxes), which is increasing and convex in the difference $[W - Z]k$ between the reported emission discharge factor and the real emission discharge factor, that is $\theta(0) = 0$, $\theta'(x) > R_2$ ($\theta'(x) > R_1$ as well, since $R_2 > R_1$) and $\theta''(x) > 0$ for $x > 0$.

We also denote $g(\cdot)$ as the firm's revenue function, which is concave and increasing in the firm's actual pollution W. We denote by W_1^* the level such that $g'(W_1^*) = kR_1$, and similarly for W_2^*. We have $\overline{W} > W_1^* > W_2^*$, where $\overline{W}$ is given by $g'(\overline{W}) = 0$. Besides the concavity of the function $g(W)$, we also assume for convenience that $g'(W)W$ is decreasing in W:[5] For a given auditing probability ρ, the firm's maximization problem is the following:

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

where

$$\begin{aligned} E\pi(\rho, W, Z) &= g(W) - ZkR_2 - \rho\theta([W - Z]k) \text{ if } Z \leq T/k \\ &= g(W) - ZkR_1 - L_0 - \rho\theta([W - Z]k) \text{ if } Z > T/k. \end{aligned}$$

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

$$\frac{\partial E\pi}{\partial W} = g'(W) - \rho k\theta'([W - Z]k) = 0,$$
$$\frac{\partial E\pi}{\partial Z} = -kR_i + \rho k\theta'([W - Z]k) = 0,$$

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

Chapter 2 characterizes firms' optimal pollution and report decisions with respect to auditing probability in this model. The following proposition complements these findings

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[5] Differentiating $g'(W)W$ with respect to W, we have $g''(W)W + g'(W)$. We note that for all "sensible" (optimal) levels of pollution W, $g'(W) \leq kR_1$ or kR_2.

by describing how the change of pollution concentration standard C^* influences a firm's actual pollution, reported pollution and expected profits.

Proposition 3 *Given an auditing probability* $\rho > 0$*:*

(a) a firm's emission W *is increasing on* C^**;*

(b) a firm's levy payment is decreasing on C^**, once it reports a positive emission;*

(c) a firm's total expected payment (levies plus penalties) is decreasing on C^**;*

(d) a firm's expected profit is increasing on C^**.*

Proof. See appendix. ■

An increase in the pollutant concentration standard C^* induces a firm to emit more pollution. The reason is straightforward: a higher concentration standard lowers the effective pollution levy rate and the penalty magnitude, hence, it decreases the marginal cost of pollution. The influence of concentration standard on a firm's reported emission Z is ambiguous. However, the firm's pollution levies are increasing on the concentration standard C^*. Even if decreasing the concentration standard may lead a firm to report more emission, the influence of the concentration standard on the effective tax rate overrides the potential increase of the reported emissions and the firm end up paying less environmental levies. This also leads the firm to lower its total expected payment and to increase profits.

3.2.3 The Bargaining Game

The result in the Proposition 1, together with firms' reaction as a function of the auditing probability, help us better understand how firms react to different levels of effective regulation. We address now the determination of the effective regulation subject to firms. We present a simple bargaining game that captures the main elements of the negotiation between local and central authorities for setting effective environmental regulation. As we described before, the central authority formulates most regulatory parameters uniformly through the country, but local authorities are also involved in determining firms' pollution concentration standards. Meanwhile, local authorities are also engaged in the enforcement of environmental regulation. Therefore, both central and local regulatory bodies set firms' effective pollution regulations.

Central and local authorities put different weights to the benefits and damages of firms' pollution. For instance, the central authority relatively pays more attention to the damages of pollution, such as public health, pollution haven effects and cross local jurisdiction pollution. It also takes into account the negative externalities of the pollution of one province or county on neighboring regions. In contrast, local governments pay more attention to the impact of environmental regulation on the local labor market, firms' profits and furthermore local economy. We take these difference into account in the simple bargaining game on the firms' concentration standard C^*. This is analogous to considering the bargaining game on the level of enforcement of environmental regulation (i.e., the number of inspections).

As we have seen in our previous analysis, for a given audit probability (inspections), a firm's emission W is monotonically increasing on its concentration standard C^*. Therefore, bargaining over C^* is equivalent to bargaining over the firm's emission W. For simplicity, we choose to present the bargaining game in terms of W.

We represent the objective function of the central authority through a function $\Pi_c(W) = B(W) - D(W)$, where $B(\cdot)$ is the benefit function of pollution (e.g., firms' profits, employment, pollution abatement investment) while $D(\cdot)$ represents the damage function of pollution (e.g., public health). As usual, we assume that both are C^1 and increasing functions. Furthermore, $B(\cdot)$ is a concave function and $D(\cdot)$ is a convex function. We define $W^c = \arg\max_W \Pi_c(W)$, the first-best pollution level from the central authority point of view. Correspondingly, the local government maximizes its objective function $\Pi_l(W) = \alpha B(W) - \beta D(W)$, where α and β are parameters that measure the relative weights (with respect to the central authority) that local authorities put on pollution benefits and damages. For instance, a large value of α reflects a comparatively large concern of the local authorities with respect to the local benefits derived from industrial activities, such as firms' profits and impact on local labor markets. In contrast, a lower value of β might reflect that the local authorities care relatively less on the damages of pollution, such as the damage to public health and the effect of pollution on neighboring regions. Again we define $W^l = \arg\max_W \Pi_l(W)$.

It seems sensible to assume that $\alpha > 1$ and $\beta < 1$. In any case, casual evidence strongly suggests that local authorities tend to be more permissive with respect to pollution than the central authority. Therefore, we assume that $W^l > W^c$, which is consistent the fact that the central authority usually has more incentives to impose stricter environmental regulation than local authorities. We define the threat point for both players as $(\Pi_c(W_f), \Pi_l(W_f))$, where W_f is the firm's emission level when the bargaining between central and local authorities is failed. W_f is assumed to be greater than W^l (namely greater than W^c too). The assumption is reasonable, because a failure in bargaining would lead to a regulation far away from efficiency (e.g., local authorities may intend not to cooperate with the enforcement actions conducted by the central authority, which induces a high cost of enforcement). Therefore, firms are better off from the failure of bargaining. Figure 4 depicts the bargaining game between local and central authorities.

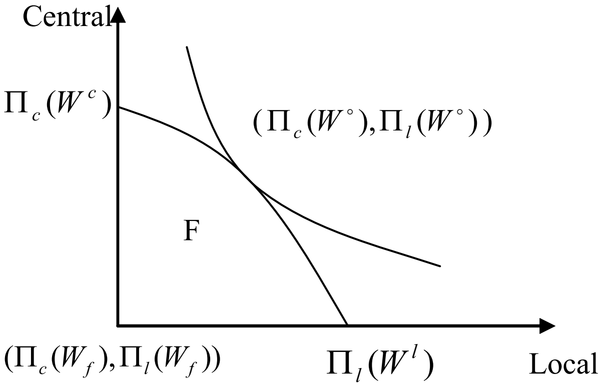

Figure 4: Bargaining game between local and central governments

The vertical and horizontal axes in Figure 4 represents the central authority and local government's payoff respectively. F denotes the feasible set, which is a convex set. Each point in the frontier of the feasible set is smooth and represents the corresponding payoffs of the central and local authorities at a emission level $W \in [W^c, W^l]$. The bargaining solution W° is found using the Nash bargaining solution concept. We are interested in the effect of the parameters α and β on the solution W°. The following proposition describes the marginal effects.

Proposition 4 *When the local authorities are more concerned with emission benefits or less concerned with emissions damages, the bargaining outcome leads to higher concen-*

tration standards and higher level of pollution, namely, $\frac{dC^*}{d\alpha} > 0$*,* $\frac{dW^\circ}{d\alpha} > 0$*,* $\frac{dC^*}{d\beta} < 0$ *and* $\frac{dW^\circ}{d\beta} < 0$*.*

Proof. See appendix. ■

The proposition above simply tells us that if local authorities put more weight on the benefits of emissions or less weight on the damages, the bargaining outcome leads to less strict pollution standards on firms' pollution, and vice versa. Through the simple game, we can understand how the bargaining over concentration standard makes regional different in firms' environmental performance.

The parameters α and β are represent firms' local conditions, such as local income/GDP per capita, local population, and so on. In principle, we expect α to be a decreasing function of local income/GDP, and increasing on the importance of the firm for local labor market (for instance, we expect α to be increasing in the unemployment rate). On the contrary, β should be an increasing function of local income/GDP, local population, percentage of people receiving higher education, environmental protection activities by NGO in local areas and local citizens' complaints on emissions.

According to our interpretation of the parameters α and β, the empirical implications of Proposition 2 are the following:

Firms located in low income/GDP per capita (higher α) should be subject to less strict effective pollution regulation (i.e., less strict pollution standards, less frequent inspections).

Firms that are important employers in the local labor market and important contributors to local GDP (higher α) are more likely to be imposed less strict effective regulation.

Less strict regulation may also be put on firms in which local governments hold stakes (higher α).

Stricter regulation should be levied on those firms whose emissions are likely to generate a higher level of damages, for instance, those firms located in population dense areas like urban areas (higher β).

Firms are likely to be subject to stricter regulation if they are located in the areas where most residents receive higher education (higher β).

Finally, stricter regulation should be imposed to those firms located in areas where citizens raise more complaints on emissions (higher β).

3.3 Empirical analysis

In this section, we empirically study how firms' local conditions matter firms' pollution concentration standards and on the number of inspections imposed on firms. We test some of the empirical implications derived from the theoretical model introduced in the previous section. We first describe the characteristics of the data involved in our study, then we set up an empirical model.

3.3.1 Data Description

Our dataset has been supplied by Fuzhou Environmental Protection Bureau and Shenyang Environmental Protection Bureau. Fuzhou is the capital city of the Fujian province in southeast China. Fuzhou's industries mainly involve food, medicine, chemical, automobile, textile and electronics sectors. State-owned enterprises do not dominate Fuzhou industry as private and foreign joint ventures have considerably increased in the last decade. It is the capital city of the Liaoning province in Northeast China. Shenyang is an important industrial center in China, and the transportation and commercial centre of China's Northeastern region. It has focused on heavy industry, particularly aerospace, machine tools, heavy equipment, and defence, and more recently on software, automotive, and electronics. Different from Fuzhou, state-owned enterprises constitute a large proportion of its economy.

The data set involves 290 plants' pollution and production information for the year 2002. Besides the plant-level data, we also include a local county level database on local economic development indicators. The plants in the sample mainly involve those large COD (Chemical Oxygen Demand) polluters and they belong to food, paper, medicine and chemical industrial sectors. Plants are located in 11 different districts/counties from the two municipal cities (4 from Fuzhou, 7 from Shenyang). Data on plant-level variables include plants' value of output, number of employees, age, COD emissions, sectors they belong to, and ownership. The dataset also integrates information on the effective environmental regulation, such as COD pollutant concentration standard and number of inspections imposed on those plants. Moreover, information on local development indicators (i.e. GDP, population) allows to capture firms' local conditions.

Before presenting the estimating model, some descriptive statistics are of interest. These statistics appear in Table I. Note first that plants are inspected quite frequently (the average number of inspections during the year 2002 is 8.58), which indicates that the main purpose of the inspections by the environmental authorities is verifying plants' pollution. Second, plants in our sample are mainly concentrated on the food and chemical sectors. However, the paper and medicine are also represented and they involve some large size plants. Third, the three types of ownership are almost equally represented. Plants with state-owned ownership are usually large scaled and have longer life span. Finally, one quarter of the plants in our sample are located in one particular county and the rest are evenly distributed across other counties.

Table I Descriptive Statistics of Sample (annual data for 290 Plants in 2002)

Variable	Mean	Standard Deviation	Variable	Mean	Standard Deviation
Value of output (10^7 yuan)	10.36	19.73	County dummy		
Number of employees	393.98	271.20	County$_{1}$	0.07	
COD discharge (Tons)	88.61	182.82	County$_{2}$	0.07	
Age (Decades)	2.4	1.31	County$_{3}$	0.25	
Inspection (Times)	8.58	5.05	County$_{4}$	0.09	
Sector dummy			County$_{5}$	0.06	
Food	0.37		County$_{6}$	0.05	
Paper	0.09		County$_{7}$	0.1	
Chemical	0.45		County$_{8}$	0.09	
Medicine	0.09		County$_{9}$	0.04	
Ownership dummy			County$_{10}$	0.12	
State owned	0.3		County$_{11}$	0.06	
Collective	0.4				
Joint Venture	0.3				
Urban dummy	0.66				

3.3.2 Models and results

Our objective is to analyze the process leading the regulator to undertake effective environmental regulations. As we have argued in the previous section, we are interested in the variation of inspection and pollution standards with plants' characteristics and local conditions. We therefore test for the impact of plants' characteristics and local conditions on the two variables: the pollution concentration standards and the number of inspections. With this purpose, we run two regressions by putting the aforementioned two variables as independent variables and plants' basic characteristics and local conditions as regressors.

As described in Section 2.1, pollution standards vary with type of pollutant and with industrial sector the plant belongs to. To avoid the problem of measuring standards corresponding to different pollutants, we only look at the standards on COD pollution. The second difficulty is that our data set involves plants from four different sectors, therefore we can not directly use the standards to measure whether a plant is subject to a strict regulation[6]. For each sector, the central authority sets three optional escalating standards for COD pollutant (labeled as first, second and third class from strict to moderate). However, the local environmental agencies in Fuzhou and Shenyang, where our sample plants are located, only implement either the first class or the second class standards for the pollution emitted in the local waterway. Therefore, we consider the choice of standard for the COD pollutant in our sample as a binary choice. We assign value 1 for those plants subject to the stricter COD standard (the first class standard) and value 0 to the rest plants, as a way to measure the strictness of the pollution standards the plants are subject to. The standard equation estimated is of the form:

$$STA_i = 1[c + \Phi' X_i + \Psi' Y_i > \eta_i]$$

where STA is the standard dummy; $1[\cdot]$ is the usual indicator function; X_i contains the plant i's basic characteristics: age, number of employee, sector and ownership; Y_i contains variables describing plants' local conditions: local population, GDP per capita, urban dummy, Fuzhou dummy, as well as the ratio of the plant's output to local GDP (to capture the relative importance of the plant to the local economy); Φ' and Ψ' are coefficient matrix, and η_i is a variable that could capture some unobserved factors influencing the

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[6] For instance, the standard of $100mg$ COD per liter wastewater is very strict for paper making plants but not strict at all for those plants that produce bread.

strictness of the standard imposed on the plant. For simplicity, we assume that η_i is identically and independently distributed normal random variable so that "the standard equation" is simply a probit model.

We expect age to be a key variable determining standards, in the sense that a less strict standard is expected to be imposed in those plants with older technology and machines. The number of employees may capture the scale effect. Given the observation that the more polluting firms (i.e., more COD emissions) are not necessary subject to a stricter standard, we don't put plants' COD pollution as a regressor. Local population and urban dummies are picked to measure how the local regulatory agencies care about the damage of plants' pollution on public health. Since the data are collected from two municipal areas, we expect that it may bring heterogeneity.

The inspection equation is estimated by a simple linear regression model of the form:

$$INS_i = c + \Pi' X_i + \Omega' Y_i + \gamma STA_i + \delta COD_i + \varepsilon_i$$

where INS stands for number of inspections on plant i; and X_i and Y_i contain the same variables as the standard equation; we also include standard dummy and COD pollution as regressors here, because we expect that the behavior of the enforcement agencies may be a function of the strictness of the standard and the level of pollution.

The estimated results of both equations are reported in Table II. Note first that plants' age has very significant impact on both the pollution standard and the number of inspections. Younger plants are subject to stricter pollution standard and less frequent inspections, which confirms our expectation. Second, the state-owned and collective plants are imposed less strict standards compared to those plants with foreign joint venture ownership. This result may be due to the fact that the latter have more advanced technology than state-owned and collective plants. The result may also due to the fact that stated-own and collective plants have more bargaining power than joint-venture plants in environmental regulation (see, Wang 2002) Third, plants with stricter pollution standards attract more frequent inspections.

Table II Standard equation and Inspection Equation

(Sample size: 290 plants)

Independent Variable	STA	INS
Age	-0.7307***	0.6585**
	(0.094)	(0.2875)
Employee	-0.0004	0.0004
	(0.0006)	(0.0015)
Food	0.1547	-2.2917**
	(0.3728)	(1.1506)
Paper	0.8901*	0.4842
	(0.4638)	(1.3757)
Chemical	0.1514	-0.2058
	(0.3736)	(1.1243)
State-owned	-1.0546***	-0.5673
	(0.2891)	(0.851)
Collective	-0.4771*	-1.2388*
	(0.2551)	(0.7154)
STA		0.6746*
		(0.3519)
COD		0.0037
		(0.3519)
Urban	0.3588*	1.0439*
	(0.2022)	(0.574)
Population	0.3816	1.2123*
	(0.2796)	(0.7007)
Output ratio	0.0008	0.2516**
	(0.0361)	(0.1117)
GDP per capita	0.1744**	0.5167**
	(0.0821)	(0.2282)
Fuzhou	-0.1485	-0.6292
	(0.2124)	(0.5524)
Constant	0.8401	3.4599*
	(0.637)	(1.8714)
R^2	0.4112	0.3165

Also compatible with the empirical implications derived in the theoretical analysis, plants' local conditions are key factors in explaining the decision on standards and inspection activities by regulatory agencies. Plants located in urban areas are subject to stricter standards and more frequent inspections. In the same spirit, greater inspection effort is allocated towards those plants whose emissions are likely to generate a higher level of damage (those plants located in the areas with more population). Moreover, plants in counties with high GDP per capita are subject to stricter effective regulations (i.e., stricter pollution standard and more frequent inspections).

3.4 Concluding remarks

In this paper, we first analyze how different levels of effective environmental regulation influence plants' decisions concerning actual and reported emissions. We then present a simple bargaining game to simulate the scenario where central and local authorities jointly determine the effective pollution regulation. Finally, we empirically study which factors have significant impacts on the effective environmental regulation (i.e., the level of strictness of pollution standards and the number of inspections) subject to firms.

We show that environmental agencies take into account firms' age and ownership when they impose plants' pollution standards and undertake inspections. We also show that besides their characteristics, plants' local conditions matter in determining their effective environmental regulation. For instance, plants located in higher GDP per capita and in urban and dense population areas, are facing stricter effective environmental regulation. These empirical results are consistent with both out theoretical analysis of plants' behavior and the results of the bargaining model that we have introduced.

Our results offer important insights into the regulator's behavior: environmental agencies do take public interests in plants' pollution into account when they determine plants' regulation. Plant's effective environmental regulation is strongly influenced by the local costs and benefits of plants' pollution, which is consistent with the principle of environmental economics, that is, environmental regulation is the outcome of balancing the economic activity and environmental degradation due to the pollution by taking all benefits and costs into account. In this sense, this paper complements the similar studies which have been conducted in North America. As its counterpart in US/Canada, the environmental regulator in China makes regulatory decisions also reflecting plants' local conditions.

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3.5 Appendix

Proof of Proposition 1. We refer to the Proposition 2 in Chapter 2 for the precise expression of firms' optimal decisions (reported emission Z and actual emission W) for a given auditing probability.

Hence, for (a), in the case where $Z = 0$, the optimal W is characterized by $g'(W) - \rho k\theta'(Wk) = 0$, namely $g'(W) = \rho k\theta'(Wk)$. It is immediate that $k = \frac{C-C^*}{C^*}$ is decreasing on C^*, that is an increase of C^* leads to a decrease in k. Then, applying the implicit function theorem to equation $g'(W) = \rho k\theta'(Wk)$ implies that a decrease in k (i.e., the increase in C^*) leads to an increase in W. When $Z > 0$, the actual emission level W^* is given by $g'(W^*) = kR$, so W^* is decreasing on k (increasing on C^*) too. Therefore, a firm's emission W is increasing on C^* for a given $\rho > 0$.

For (b), when a firm reports a positive emission (namely $Z > 0$), the interior solution of Z requires: $-kR + \rho k\theta'([W^* - Z]k) = 0$, i.e., $\theta'([W^* - Z]k) = \frac{R}{\rho}$. Since $\frac{R}{\rho}$ does not depend on C^*, $[W^* - Z]k$ (namely, $W^*k - Zk$) is a constant too. Moreover, in the region where $Z > 0$, the actual emission level W^* is given by $g'(W_i^*) = kR$. Multiplying both sides of $g'(W_i^*) = kR$ by W^*, we obtain $g'(W^*)W^* = kRW^*$. Given the assumption that $g'(W)W$ is decreasing on W, we have that kRW^* is also decreasing on W^* and therefore decreasing on C^*, because of property (a). Since R is a constant, we have shown that kW^* is decreasing on C^*. Combined with the fact that $W^*k - Zk$ does not depend on C^*, we have Zk is decreasing on C^*. Therefore, the firm's levy payment ZkR is decreasing on C^*.

For (c), if $Z = 0$, total expected payment (levies plus penalties) is simply $\rho\theta(Wk)$. We have that the optimal W is given by $g'(W) = \rho k\theta'(Wk)$. Multiplying both sides by W, we obtain $g'(W)W = \rho Wk\theta'(Wk)$. Given the assumption that $g'(W)W$ is decreasing on W, we have that $\rho Wk\theta'(Wk)$ is decreasing on W and then on C^*, so Wk is decreasing on C^*. Therefore, $\rho\theta(Wk)$ is decreasing C^*. If $Z > 0$, the total expected payment is $ZkR + \rho\theta([W^* - Z]k)$. By part (b), we know that $[W^* - Z]k$ does not depend on C^*, while the levy payment ZkR is decreasing on C^*. Therefore, $ZkR + \rho\theta([W^* - Z]k)$ is decreasing on C^*.

For (d), follows immediately after (a) and (c). ■

Proof of Proposition 2. According to the definition of the Nash Bargaining solution,

$W^\circ \in \arg\max_W \{\ln[\Pi_c(W) - \Pi_c(W_f)] + \ln[\Pi_l(W) - \Pi_l(W_f)]\}$.

The FOC implies

$\frac{\Pi_c'(W^\circ)}{\Pi_c(W^\circ)-\Pi_c(W_f)} + \frac{\Pi_l'(W^\circ)}{\Pi_l(W^\circ)-\Pi_l(W_f)} = 0$.

We now apply the implicit function theorem, differentiating both sides with respect to α, we have,

$\frac{\partial W^\circ}{\partial \alpha} = \frac{\{[\alpha B''(W^\circ)-\beta D''(W^\circ)][B''(W^\circ)-\beta D''(W^\circ)]-[B'(W^\circ)-D(W^\circ)]B(W^\circ)\}[B(W^\circ)-D(W^\circ)-B(W_f)+D(W_f)]^2}{[\alpha B(W^\circ)-\beta D(W^\circ)-\alpha B(W_f)+\beta D(W_f)]^2}$. Given that both $\Pi_c(W)$ and $\Pi_l(W)$ are concave functions and $W^\circ > W^c$, we obtain $\frac{\partial W^\circ}{\partial \alpha} > 0$. The proof is similar for $\frac{\partial W^\circ}{\partial \beta} < 0$. Since the emissions W is monotonically increasing on C^*, we also obtain $\frac{\partial C^*}{\partial \alpha} > 0$ and $\frac{\partial C^*}{\partial \beta} < 0$. $\blacksquare$

Chapter 4

Strategic Self-reporting and Firms' Compliance with Environmental Regulations in China

4.1 Introduction

A large amount of literature has studied the economics of monitoring and enforcement of environmental regulations, particularly in North America. Given the dominance of pollution standard regulations in the US and Canada, the literature has generally focused on the determinants of compliance with legal standards[1].

Different from the pollution regulation in North America, a pollution fee/tax (so called pollution levy) system has been imposed on firms' pollution in China. The different regulations existing in US/Canada and China lead to different contexts of enforcement. In particular, enforcing pollution standards focuses on making firms' pollutions up to the corresponding standards, while enforcement of pollution levies targets on ensuring that firms pay levies for each unit of emission.

Enforcement of environmental regulations not only involves actions conducted by environmental authorities such as on-site inspections and penalties for noncompliance. It also includes self-monitoring: polluters must self report their pollution to environmen-

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[1] See, for instance, Magat & Viscusi (1990), Laplante & Rilstone (1996), Dumas & Devine (2002) and Shimshacka & Ward (2005, 2007).

tal agencies. It is commonly accepted in the literature of enforcement and compliance that self reporting saves large amount of resources to regulatory authorities and therefore improves regulated agents' compliance with regulations[2]. However, a problem that may naturally arise here is that firms' self-reporting may not be accurate, or even that it may greatly deviate from actual pollution.

Previous studies on enforcement mostly focus on how and to which extent inspections and penalties for noncompliance lead the firms to better comply with environmental regulations. For instance, in the context of standard regulation, Magat & Viscusi (1990) and Laplant & Rilstone (1996) analyzed the impact of inspections on the emission level of plants in the pulp and paper industry in US/Canada. They concluded that inspections have a strong negative impact on pollution emissions. Under the pollution levy system in China, we have shown in Chapter 2 that inspections also lead Chinese polluters to improve their environmental performance. However, they are mainly effective in verifying firms' self-reported pollution, they do not seem to lead to a reduction in actual pollution as in US/Canada. The current chapter deviates from the previous studies by focusing on how inspections and fines conducted by environmental agencies improve firms' self-monitoring. In particular, we investigate how firms strategically report their pollution under China's specific pollution regulation.

Although levy rates and structure have been amended several times, the procedure of firms' self-reporting has never been adjusted since the levy system was enacted. At the beginning of a year, firms are required to renew their pollution discharge licenses for the coming year. Meanwhile, firms are also required to make an ex ante report on their monthly/quarterly pollution (uniform for each period) in the coming year. If there happens a big change, for instance a change in the pollution abatement investment, production process or production volume, which induces a firm's actual pollution level to deviate significantly from the ex ante report, the firm is liable to modify its previous report (by either increasing or decreasing it). The modification is supposed to be effective unless there is another modification afterward. Firms' reports are verified by on-site inspections. Finally, according to firms' self reports and environmental agencies' verifications, firms pay pollution levies and, eventually, monetary penalties. Monetary penalties (fines) are

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[2] See Harford (1987), Malik (1993), Kaplow & Shavell (1994), Heyes (1996), Mishra et al. (1997) and Livernois & McKenna (1999).

not only imposed on the firms that are caught for underreporting their pollution, but also on those firms, who do not invest and install pollution abatement equipment properly and who are responsible for environmental accidents such as the release of a toxic substance into a reservoir, sighting medical waste on a beach or a train derailment or a leaking pipeline.

Unlike the usual ex post self-reporting, the procedure of ex ante self-reporting gives firms a large room to strategically underreport their pollution, since they can modify their reports as a function of the number of inspections they suffer. The procedure offers firms extensive flexibility in making self reports. For instance, since the ex ante reports are based on predictions, firms can underreport their pollution without being subject to penalties on false reporting. Given the specific ex ante self reporting procedure, it is of interest to analyze whether enforcement actions by environmental authorities significantly affect firms' decisions on modifying their report.

By adopting a unique data set on enforcement and firms' self-reporting, we analyze whether and how firms strategically report their pollution. Firms' ex ante reported emissions are significantly below the verified levels on which firms pay pollution levies. We show that the enforcement actions by environmental agencies significantly explain firms' decision on modifying their ex ante reports. We estimate that each inspection (fine) increases the firms' likelihood of modification by 19.62% (64.3%). Moreover, each inspection (fine) increases the firms' likelihood of increasing previous reports by 22.49% (28.85%). The study, together with that developed in Chapter 2, provides clear evidence that, under China's specific pollution levy system, firms significantly underreport their pollution and enforcement actions by environmental agencies are mainly effective in inducing firms to report their pollution more accurately.

There are few empirical studies on the quality of firms' self reported pollution data. Assessing the accuracy of self-reported pollution data has been approached in the literature in two ways: (1) check whether self-reported discharges differ from findings of the regulator through a paired difference-of-means test or (2) simply argue that systematic misreporting cannot prevail due to the presence of penalties, whistleblowers and other deterrent factors. The second approach is still not very reassuring while the first approach is possible only when certain types of observations are available (e.g. Laplante & Rilstone, 1996). A new and more conclusive technique to assess the accuracy of self-reported pollution data has emerged from a surprising statistical property called the Significant-Digit Law, known more popularly as Benford's Law. It states that if distributions are selected randomly in any "unbiased" way and random samples are then taken from each of these distributions, the significant digits of the combined sample will converge to the logarithmic or Benford distribution. Auditors have recently exploited this property to detect fraud in accounting data (Durtschi et al., 2004). Dumas & Devine (2002) were the first to outline the applicability of Benford's law to pollution data and they tested it out on criteria air pollutant emissions figures from North Carolina firms. More recently, De Marchi & Hamilton (2006) applied tests based on Benford's Law to chemicals in the U.S. Toxics Release Inventory (TRI). They found that the air emissions reported by firms in the TRI are not always matched by the measured concentrations from EPA monitors.

Given the specific procedure of self reporting in China, we assess the accuracy of self-reported pollution data by identifying whether and to which extend inspections and fines lead to firms' modification of ex ante reports. The rest of this chapter proceeds as follows. In section 4.2, we present and describe our data set. In section 4.3, models and results are presented. We conclude in section 4.4.

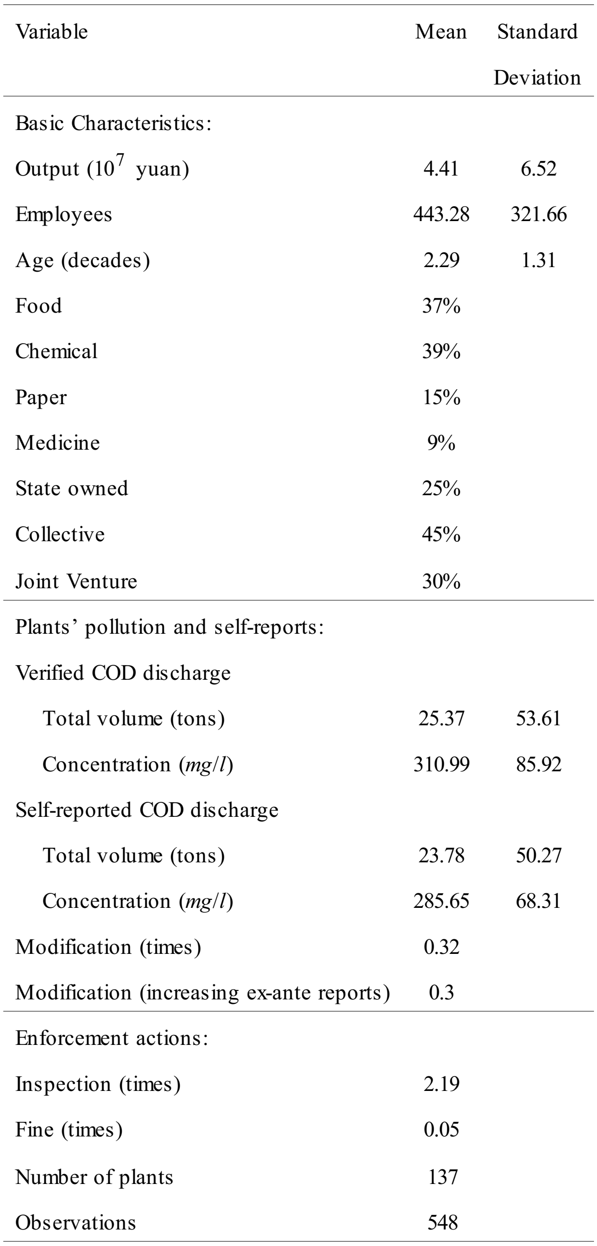
4.2 Dataset

We adopt a dataset which has been supplied by Fuzhou Environmental Protection Bureau (FEPB) and supplemented by Fuzhou Bureau of Statistics. Fuzhou is the capital city of Fujian province located in the southeastern coast of China. The industrial sector is the most important economic sector of Fuzhou. Its industrial growth has been extremely rapid during the period of China's economic reform. Over the course of the last decade, Fuzhou's industrial output increased at an average annual rate of 12%. The Fuzhou Economic & Technical Development Zone was established in 1985 and it has already attracted over 13.6 billions dollars foreign investments from 30 countries and regions.

The dataset contains quarterly observations of 137 plants' pollution and production for the year 2002. It involves the same set of plants as employed in Chapter 2. They are all main COD (Chemical Oxygen Demand) polluters. Besides the plants' information considered and analyzed in Chapter 2, here we also include the information on these plants' self-reports, which allows us to identify whether plants strategically report their pollution under the China's specific self-reporting procedure.

Table I Descriptive Statistics of Sample

(Quarterly Data 2002:1–2002:4)



Variable	Mean	Standard Deviation
Basic Characteristics:		
Output (10^7 yuan)	4.41	6.52
Employees	443.28	321.66
Age (decades)	2.29	1.31
Food	37%	
Chemical	39%	
Paper	15%	
Medicine	9%	
State owned	25%	
Collective	45%	
Joint Venture	30%	
Plants' pollution and self-reports:		
Verified COD discharge		
Total volume (tons)	25.37	53.61
Concentration (*mg/l*)	310.99	85.92
Self-reported COD discharge		
Total volume (tons)	23.78	50.27
Concentration (*mg/l*)	285.65	68.31
Modification (times)	0.32	
Modification (increasing ex-ante reports)	0.3	
Enforcement actions:		
Inspection (times)	2.19	
Fine (times)	0.05	
Number of plants	137	
Observations	548	

The descriptive statistics of the data are shown in Table I. As described in Chapter 2, plants in our sample focus on four sectors: Food, Chemical, Paper and Medicine; and the three types of plants' ownerships are well represented. The variables of *verified COD discharge* describe the level of plants' COD emissions (in each quarter) after being verified by environmental agencies. This is the level according to which plants pay pollution levies. The variables of *self-reported COD discharge* represent the level of plants' COD emissions as reported by the plants themselves at the beginning of 2002. As indicated in Table I, both plants' average self-reported COD discharge volume and concentration are less than the corresponding verified levels. In our sample, we observe that a total of 177 modifications were conducted by the 137 firms during the year 2002 (with an average of 0.32 modifications per firm and per quarter). Among these modifications, most of them (163) increase the previous self-reported COD emissions (average of 0.30 increased report per firm and per quarter). We also include the information on fines imposed on plants. A total of 27 fines was imposed on plants (with an average of 0.05 times per firm and per quarter). For each fine in our dataset, a modification is observed.

To compare ex ante reported emission and verified emission, we would ideally like to run a simple test of the differences between inspectors' measurement and plants' self-reported COD emissions. However, the on-site inspection data (inspectors' measurement of firms' pollution by each on-site visit) are not yet available to us. Alternatively, we compare plants' verified self-reported emissions on which plants pay levies and ex ante self-reported emissions. We expect that the verified self-reported emissions represent a good proxy for inspectors' measurements on plants' emissions.

As shown in Table II, the resulting test statistics indicate that both firms' self-reported COD concentration and volume significantly fall below their verified concentration and volume. Firms systematically under report their pollution. This behavior is partly due to the specific ex-ante self reporting procedure in China, which provides firms room to report strategically.

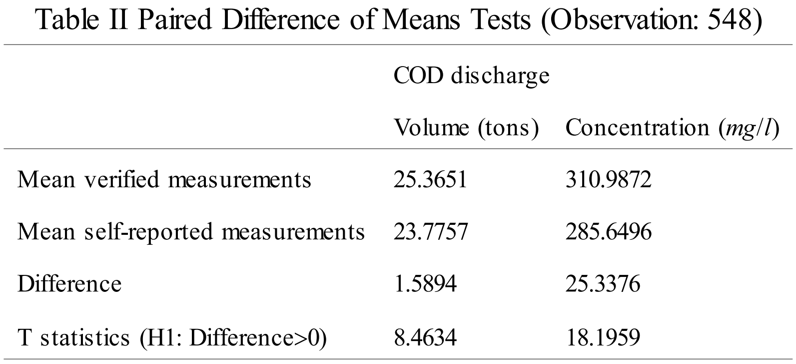


Table II Paired Difference of Means Tests (Observation: 548)

	COD discharge	
	Volume (tons)	Concentration (*mg*/*l*)
Mean verified measurements	25.3651	310.9872
Mean self-reported measurements	23.7757	285.6496
Difference	1.5894	25.3376
T statistics (H1: Difference>0)	8.4634	18.1959

Figure 4.2.1:

4.3 Model and estimation

In this section, we test for the impact of regulatory actions on two sets of variables: the dummy variable that states whether a plant has modified its report (either increase or decrease) in a quarter (value 1) or not (value 0) and the dummy variable that states whether a plant has increased its report in a quarter (value 1) or not (value 0).[3] The impact of regulatory actions (both inspections and fines) are expected to be significant on plants' modification of their reports and on both plants' increasing their reports. The model we estimate is of the same form regardless of the modification variables of interest.

Let $M_{i,t}$ denote the modification variables associated with plant i in quarter t. The equations estimated are of the forms:

$$M_{i,t} = 1[c + \beta_1 INS_{i,t} + \beta_2 FINE_{i,t} + \beta_3 \triangle Output_{i,t} + \beta_4 M_{i,t-1} + \beta_5 t + \Psi' X_i > \varepsilon_{i,t}]$$

Where $1[\cdot]$ is the usual indicator function; $INS_{i,t}$ and $FINE_{i,t}$ correspondingly represent inspections and fine subject to plant i at period t; $\triangle Output_{i,t}$ captures the relative change of plants' output in current period with respect to the one in last period. Output variable is, as in Chapter 2, a proxy of plants' actual emissions. In the regression

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[3] It is also interesting to run the regression by putting the dummy variable that states a plant has decreased its report as dependent variable, but in our dataset the observations of plants' decreasing their reports are too few.

equation where $M_{i,t}$ denotes plants' modification on their reports (either increase or decrease), $\triangle Output_{i,t}$ takes its absolute value, namely $|(Output_{i,t} - Output_{i,t-1})/Output_{i,t-1}|$ because we expect that the more a plant's output deviates from its previous level, the more likely the plant modifies its self report. However, in the regression equation where $M_{i,t}$ denotes plants' increasing their reports, we expect that the more a plant's output is above its previous level, the more likely the plant increase its self report. Therefore, we do not need to make absolute operator on $\triangle Output_{i,t}$. $M_{i,t-1}$ denotes the one period lagged dependent variable. We expect that a firm is less likely to modify its report if there is a modification conducted in the previous period. We also put quarter index t as a regressor. Given the procedure of self-reporting, a modification is more likely to be undertaken at a period away from the beginning of the year at which the ex-ante report is made. X_i is a set of variables involving plants' age, number of employee, ownership and sector and $\varepsilon_{i,t}$ is a variable which could capture, for example, some unobserved tolerance level above which a modification is conducted. For simplicity, we assume that $\varepsilon_{i,t}$ are normal random variables independently distributed but different across plants (we control them by using clusters robust in plants), so that the estimation equations are simply estimated by the probit model.

The estimation results are presented in Table III. First note that, the inspections conducted are, as expected, positive and have strong effect on plants' modifying their reports, especially on plants' modification in increasing their reported pollution. Each inspection carried out in the current quarter increases plants' likelihood of modification by 19.62% and plants' likelihood of increasing self reports by 22.49%. Second, the coefficients of fines are positive and very statistically significant. In particular, each fine induces plants more likely to modify their reports by 64.3% but to increase their reported pollution by 28.85%. Different from the inspection variable, each fine has stronger impact on plants' modification than on plants' increasing their reports. The reason is that fines are not only imposed on those plants who underreport their pollution, but also on those plants who do not appropriately install and maintain pollution abatement equipment. In the former case, fines lead plants to report their pollution more truthfully by increasing their report, but in the latter case fines improve plants' efforts in abating pollution and induce plant's modification of decreasing their reports.

Table III Modification Equations

(Sample size: 411)

Independent Variables	Modi.	Modi. (Incr.)
INS_t	0.5199***	0.5809***
	(0.0627)	(0.0735)
$Fine_t$	1.9309***	0.7387***
	(0.5666)	(0.2832)
$\triangle Output_t$	-1.4009	1.2976**
	(1.1972)	(0.6398)
M_{t-1}	-0.5565***	-0.4677***
	(0.1659)	(0.1788)
t	0.1332	0.1992**
	(0.0908)	(0.0952)
Age	-0.1026	-0.0802
	(0.0808)	(0.0803)
Employee	-0.0002	-0.0001
	(0.0003)	(0.0003)
Food	0.2585	0.1141
	(0.2560)	(0.2420)
Chemical	0.1012	-0.0582
	(0.2243)	(0.2044)
Paper	0.3024	0.1382
	(0.2753)	(0.2725)
State-own	-0.1281	-0.1520
	(0.2361)	(0.2422)
Collective	0.0529	-0.0114
	(0.2004)	(0.2009)
Constant	-1.6550***	-2.1617***
	(0.4452)	(0.4580)
R^2	0.2633	0.2569

Cluster robust with firms

In the model where we put modification of increasing as dependent variable, the effect of fine on plants' modification of decreasing their reports is neglected. Third, $\triangle Output_t$ has positive and significant effect on plants' increasing their reports, which confirms our expectation that the more a plant's output is above its previous level, the more likely the plant increase its self report. Fourth, the coefficients of the one period lagged dependent variable are always negative and very statistically significant, which indicates that a modification conducted in the previous period makes the plant less likely to modify its report. Finally, the coefficients of quarter index variable (t) are always positive, but not always statistically significant. The result shows that plants' modifications of increasing their reports are more likely to be conducted in the quarter that is longer away from the beginning of the year, which provides evidence that at the beginning of a year plants intend to underestimate their pollution in the coming year.

A question which arises in the context of this study concerns the possible endogeneity of enforcement actions (inspections and fines) and the consequent inconsistent estimation on the probit model. If inspections and fines are endogenous and correlated with the same variables which determine plants' modification of their reports, then the estimation in Table III will be biased in general. Interviews with the employees of FEPB indicate that a plant's modification of its report may trigger further inspections, especially when the modification involves for instance an accident happened to the plant's pollution abatement equipment, the change of production process, and the change of major inputs. In contrast, we think the variable fine is not endogenous in the estimated probit model as we confirmed with the employees of FEPB: for each fine there is a modification that probably follows, but not the other way around. Therefore, we focus on the possible endogeneity problem of inspections. To control this, it is necessary to model the inspections using some variables that do not enter the basic probit model. As in Chapter 2, we take citizens' complaints as the instrument variable. Citizens' complaints trigger inspections but not directly lead plants to modify their reports. We take the equation of modification with increasing reports as an example and run the probit regression with instrument variable (See appendix). The Wald test of exogeneity is then used to decide if the proposed model of endogeneity is the right decision to use. The null hypothesis of Wald test (that there is no endogeneity inherent) is not rejected (with p-value 0.789 see appendix for details) and therefore the use of instrumental probit model is not supported.[4] Hence, the ordinary probit model (as shown in Table III) is found to be sufficient, given the instrument we have.

4.4 Concluding remarks

We have examined how plants strategically report their pollution under China's specific procedure of plants' self reporting. We have provided strong evidence that plants systematically underreport their pollution. We have also shown that both inspections and fines help explaining plants' decisions on modifying and increasing their reported pollution. The more the plants' verified pollutions go beyond their reported levels, the more likely the plants increase their ex ante reported pollutions. Plants are less likely to modify their reports if a modification happens to them in the previous quarter.

This paper, together with Chapter 2, allows to better understand how plants comply with China's environmental pollution levy regulation. Our studies offer clear evidence that under the pollution levy system, plants have strong incentives to evade pollution levies. Consequently, enforcement actions by environmental agencies in China mainly focus on verifying plants' pollution, unlike the enforcement actions by their counterparts in US/Canada that provide marginal deterrence on plants' noncompliance with pollution standards. Therefore, in order to improve polluters' environmental performance in China, it is necessary to reform the current pollution levy system.

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[4] We also run the Durbin-Wu-Hausman test. The result is similar to the Wald test: the exogeneity of inspections is not rejected.

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4.5 Appendix

The results of probit regression with instrument variable (411 observations, cluster robust 137 firms):

	First stage	Second stage
Independent	Inspection(INS_t)	Modi.
Variables		(Incr.)
Citizens'	1.2801***	
Compliant	(0.1510)	
INS_t		0.6369***
		(0.2398)
$Fine_t$	0.5188**	0.7132**
	(0.2266)	(0.3141)
$\triangle Output_t$	-2.7415***	1.4841
	(0.4555)	(0.9807)
M_{t-1}	-0.1957	-0.4475***
	(0.1265)	(0.1734)
t	0.1614	0.1862**
	(0.0530)	(0.1085)
Age	0.2801***	-0.0962
	(0.0861)	(0.1056)
Employee	0.0012***	-0.0002
	(0.0004)	(0.0003)
Food	-1.3595***	0.1945
	(0.2724)	(0.4010)
Chemical	-0.6681***	-0.0225
	(0.2504)	(0.2460)
Paper	-1.1367***	0.2012
	(0.2876)	(0.3599)
State-own	-0.0362	-0.1540
	(0.2690)	(0.2454)
Collective	-0.1931	-0.0022
	(0.2074)	(0.2153)
Constant	1.6090***	-2.2416***
	(0.3478)	(0.5923)
Wald test of exogeneity: chi2(1)=0.07 Prob>chi2=0.7890		

The Wald test of exogeneity simply asks whether the error terms in the structural equation (second stage) and the reduced-form equation for the endogenous variable (first stage) are correlated. If the correlation parameter is significantly different from zero, then the null hypothesis (exogeneity) is rejected and the estimations of the ordinary probit model are biased in general; otherwise the ordinary probit model is sufficient.[5]

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[5] See Wooldridge (2002, pp. 472-477).