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Financial incentives and endogenous enforcement in China's pollution levy system

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Abstract

Using data from 3000 Chinese factories, we estimate an econometric model of endogenous enforcement in which factories' levy rates and emissions are jointly determined by the interaction of local and national enforcement factors, abatement costs and regulator–manager negotiations that are sensitive to plant characteristics. Our results demonstrate the significant deterrent impact of a system that combines progressive financial penalties and self-reporting with few options for contesting regulatory decisions, despite the prevalence of state enterprises and developing-country conditions in China. Despite central pressure for uniformity in enforcement, we find great regional diversity that reflects local conditions. We also find that pollution control through financial incentives has a much greater impact on production processes than on end-of-pipe abatement.

Keywords: Industrial pollution; Pollution charge; Effectiveness; Enforcement

1. Introduction

An extensive literature has analyzed the economics of monitoring and enforcement of environmental regulations, particularly in North America [18]. Given the dominance of command-and-control methods in the US and Canada, the literature has generally focused on the determinants of compliance with legal standards. In this context, earlier work by Becker [2] on the economics of crime and punishment has provided a natural point of departure: the law enforcement agent (the regulator) attempts to identify and penalize the perpetrator (non-compliant polluter). In the basic model, non-compliance earns a fixed penalty, whose expected value depends the probability of identification and conviction. The polluter's compliance decision

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turns on a comparison of the cost of compliance (reduced emissions) with the expected penalty for non-compliance [1]. To induce greater compliance, the regulator can either raise the penalty or strengthen monitoring and enforcement.

Extensions of the basic model have recognized that polluters have options beyond a binary compliance decision. The literature on marginal deterrence, for example, relates the polluter's expected penalty to the degree of non-compliance [33]. The polluter has a two-stage decision: whether to comply and, if not, how far to carry non-compliance. Models of contested enforcement give polluters another option, by assuming that they can challenge regulatory decisions in court [21,26]. Legal challenges raise the cost of enforcement and, if successful, reduce or eliminate the penalty for non-compliance. A cost-minimizing polluter may choose a mixed strategy, which includes pollution reduction, legal action, and payment of the penalty associated with a certain degree of non-compliance.

Other studies have documented the informal web of relationships that characterize regulator–firm interactions in a multi-period and/or multi-plant context. From the regulator's perspective, tradeoffs across periods and facilities may lead to superior overall compliance than adherence to a single policy for all pollution sources [12,15,19,39].

While theoretical extensions of the basic model are numerous, related empirical exercises have been relatively sparse and, restricted largely to analyses of regulatory experience in the US and Canada [9,11,13,22,25]. These studies provide insights into regulator and firm behavior under a command-and-control system with fixed regulations, inspections that are costly (for both regulators and polluters), and plentiful legal options for polluters.[1]

In this paper, we use recent data from China to study regulator–polluter interactions in a very different setting. Like the US and Canada, China has national emissions standards for air and water polluters. However, China uses economic, rather than legal, instruments to penalize non-compliance. Its pollution levy system charges above-standard emissions on a scale that escalates with the degree of non-compliance. In this respect, the Chinese system adheres more closely than North American systems to the model presented in the theoretical literature on marginal deterrence.

China's economic response to non-compliance gives its firms more decision flexibility than the legalistic response of US and Canadian regulators. However, North American legalism provides polluters with an important degree of freedom that is largely denied to Chinese firms: the right to contest government compliance rulings in the courts. Without the contested enforcement option, mixed strategies for Chinese firms involve only two options: paying directly for non-compliance, or taking measures to reduce pollution.

Another difference lies in the prevalence of self-reporting. Russell [29] finds that state environmental agencies in the US require 28% of air polluters and 84% of water polluters to report their emissions. In contrast, self-reporting (with verification by local regulatory authorities) is a universal requirement for Chinese air and water polluters. Numerous studies [8,20,23,24] have suggested that self-reporting can improve regulatory efficiency through a variety of channels: lower monitoring and enforcement costs; superior information from honest managers, etc. In this dimension, Chinese regulators may well have an advantage over their North American counterparts.

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[1] In this paper, we do not consider more recent innovations, such as the SO_2 permit trading system.

In another dimension, China's system seems less favorable for pollution control. Until recently, the great majority of Chinese firms have been state-owned enterprises. In the sample of firms used for this analysis, over 90% are state-owned. A priori, we might assume that economic instruments would be less effective than legal instruments in reducing pollution from state enterprises with soft budget constraints. One countervailing force is introduced by the use of funds collected by the pollution levy: for polluters that install pollution control equipment during a particular year, the regulatory authority can rebate up to 80% of cumulative levy payments for cost recovery.

In the domain of "informal" pollution control (community influence on regulators and polluters), the available evidence suggests some similarity between the Chinese and North American cases. In both countries, through a variety of channels, higher-income, higher-education areas induce industry to operate at lower pollution intensity [17,37].

To summarize, China's pollution control system differs from its North American counterparts in several ways: financial rather than legal penalties for non-compliance; the absence of legally contested enforcement; universal self-reporting; the prevalence of state enterprises with soft budget constraints; and the use of pollution funds to support cost-recovery for pollution control investments. In the domain of "informal" regulation, however, the limited available evidence suggests that similar forces are in operation.

Enforcement of pollution control in China appears to be endogenous at the micro-level for several reasons. First, China pursues a marginal deterrence strategy using the pollution levy, an economic instrument. This enables Chinese firms to view emissions as "use of environmental services", whose optimal level is subject to the same cost calculus as other inputs to production. Second, Chinese firms still face the Becker problem in the dimension of self-reporting. Because the pollution levy rises with the degree of non-compliance, Chinese firms must decide whether to report their emissions honestly. There are significant legal penalties for failure to do so, and "optimal" misreporting would equate the expected marginal savings on the pollution levy to the expected penalty for misreporting. Third, it is possible that regulators' sensitivity to some firm characteristics affects the actual levy charged, whatever the formal legal requirement. At the most pragmatic level, for example, regulators may recognize a natural upper bound on penalties introduced by firms' wealth constraints or general financial condition [28,32]. Other potentially sensitive factors in China include ownership (state vs. private), plant age, and significance as a local employer.

In this paper, we specify and estimate a model of endogenous enforcement using newly available data for 3000 Chinese air and water polluters. For each enterprise, the pollution levy and emissions are jointly determined by relative abatement costs, firm characteristics, regulator characteristics, and local environmental conditions. Besides testing the significance of these exogenous factors, our study provides new insight into the effectiveness of market-based pollution control in a developing-country context. Since the levy is firm-specific in our model, we are able to estimate the elasticity of firm response to changes in this economic instrument. Our data are also sufficiently detailed for us to discriminate between two types of response: end-of-pipe pollution control, to remove process-generated waste, and process modification, to reduce waste generation during production. To our knowledge, this is the first econometric study that simultaneously addresses endogenous enforcement, firms' emissions response to pollution charges, and the division of their response into end-of-pipe and process changes.

The remainder of the paper is organized as follows. Section 2 provides a more detailed introduction to China's pollution levy system, while Section 3 describes the database and develops our econometric model. We report our econometric results in Section 4, and provide a summary and conclusions in Section 5.

2. China's pollution levy system

2.1. Background

China's industrial growth has been extremely rapid during the period of economic reform. In the 1990s, the output of the country's millions of industrial enterprises has increased by about 15% annually.[2] Industry is China's largest productive sector, accounting for 47% of its gross domestic product and employing 17% of the country's total labor force in 1995.[3] As a source of rapidly expanding income, Chinese industry has helped lift tens of millions of people out of poverty. Unfortunately, serious environmental damage has accompanied this rapid growth. In many urban areas, atmospheric concentrations of pollutants such as suspended particulates and sulfur dioxide routinely exceed World Health Organization safety standards by very large margins [31].

Chinese industry is a primary source of this problem. China's State Environmental Protection Administration (SEPA) estimates that industrial pollution accounts for over 70% of the national total, including 70% of organic water pollution (COD, or chemical oxygen demand); 72% of SO_2 emissions; and 75% of flue dust (a major component of suspended particulates) in 1995.[4] Many polluting industries are located in densely populated metropolitan areas, where emissions exposure can cause particularly serious damage to human health and economic activity.

One of China's responses to this problem has been its pollution charge, or levy, system.[5] Almost all of China's counties and cities have implemented the levy. From its inception in the early 1980s through 1998, Chinese regulators collected about 40 billion RMB yuan ($US 4.9 billion).[6] Charges are levied for 29 water pollutants and 22 air pollutants, as well as solid waste, radioactive waste, and noise.[7] Among pollutants, the major focus for monitoring and levy collection is on COD and TSS (total suspended solids) for water, and SO_2 and flue dust for air. As Table 1 shows, water pollution charges contribute the largest share of the total.[8]

Funds from the pollution levy have been used for pollution source control, damage remediation and development of environmental institutions. As of 1994, about 4.5 billion yuan of levy

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[2] During this period, the corresponding growth rates were 1.1%, 4.4% and 2.6%, respectively, for low, middle and high income countries [38].

[3] In this context, industry is a broad category that includes activities other than agriculture, services, and government.

[4] Source: SEPA [31].

[5] Other policy instruments include legal standards and executive orders. For further discussion, see Sinkule and Ortolano [34].

[6] One US dollar is approximately equal to 8.2 RMB yuan.

[7] China's levy rates reflect many impact factors, including human health damage, direct economic damage, and associated natural resource degradation. Because of this variety, there is no apparent correlation between pollutants' levy rates and their scientifically estimated impacts on human health.

[8] Water discharge standards are more stringent and the water pollutant charge rates are higher.

Table 1
Pollution levy collection in China (10^4 RMB yuan)

Year	Total	From emissions above standards					From wastewater discharge fee	From penalties	From SO_2 fee
		Water	Air	Solid waste	Noise	Radioactive wastes			
1992	239,452	118,673	50,859	3079	8930	1037	8485	48,389	
1993	268,013	122,838	56,021	3746	11,930	20	12,637	60,821	
1994	309,757	132,197	64,498	3199	15,551	89	20,046	74,177	
1995	371,281	150,365	74,297	4846	19,019	166	25,384	97,204	
1996	409,594	155,135	67,212	3743	21,413	183	28,791	118,542	14,575
1997	454,332	164,194	67,682	5015	24,417	151	30,521	139,799	22,553
1998	490,194	163,746	65,491	4394	26,410	77	28,281	150,285	51,510

collections had been used for development of environmental institutions, 3.1 billion yuan for purchasing monitoring equipment, and 1.4 billion for environmental education and environmental staff training. However, the lion's share has been used for pollution abatement. Pollution levy funds have provided about 15% of China's total expenditure for pollution control, and as much as 30–40% in some cities. As of 1995, the levy had financed or co-financed about 220,000 pollution control projects, with abatement capacity sufficient for 16 billion tons of wastewater, 4 billion cubic meters of waste gas, 70 million tons of solid waste, and 19,000 noise sources.

2.2. Development of the levy system

Discussion of a possible pollution charge system began in China after the Stockholm Conference on the Human Environment in 1972. The idea was formally adopted by the central government in 1978, when the Leaders Group for Environmental Protection in the State Council provided a report to the Central Committee of the Chinese Communist Party. The report stated that "Pollution source control should be an important component of environmental management; fees should be charged against pollution discharge; and environmental protection authorities, in cooperation with other departments, should set up a detailed levy schedule". Article 18 of the "Trial Environmental Protection Law", which was 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 programs of some type.

After studying these local experiences, the central government issued an "Interim Procedure on Pollution Charges" in February, 1982. The procedure defined the system's objectives, principles, levy standards, levy collection methods, and principles for use of the funds collected by the levy. Nationwide implementation of the national levy procedure rapidly followed.

The levy system is based on discharge standards, and only discharges exceeding the standards were subject to a fee before 1993. More recently, levies at lower rates have also been imposed on within-standard water and air emissions.[9] Although the regulations do not exempt polluters from legal liability for above-standard discharges, legal actions against non-compliant firms have been extremely rare.

2.3. Design of the levy

China's national discharge standards have been designed to promote a level of ambient environmental quality that is consistent with the country's average level of development. Levies for wastewater discharges are calculated as follows:

$$P_{ij} = \mathrm{Max}\left[0,\, W_i \frac{C_{ij} - C_{sj}}{C_{sj}}\right],$$
$$L_{ij} = \left.\begin{array}{c} L_{0j} + R_{1j}P_{ij} \\ R_{2j}P_{ij} \end{array}\right\}\left\{\begin{array}{l} P_{ij} > T_j, \\ P_{ij} < T_j, \end{array}\right. \qquad (1)$$

where, for facility i and pollutant j, P_{ij} is the discharge factor, W_i the total wastewater discharge, C_{ij} the pollutant concentration, C_{sj} the concentration standard, L_{ij} the total levy, L_{0j} the fixed payment factor, T_j the regulatory threshold parameter, R_1 and R_2 are charge standards with $R_2 > R_1$; and for continuity at T_j, $R_{2j}T_j = L_{0j} + R_{1j}T_j$.

The wastewater levy formula incorporates both concentration and volume, since it calculates a pollutant-specific discharge factor (P) based on both total wastewater discharge and the degree to which pollutant concentration (C) exceeds the standard (C_s). The charge is zero when the pollutant concentration (C) is less than or equal to the standard (C_s), which is jointly set by the central and local governments. The charge rate (R) is determined relative to a critical factor (T); both R and T are set by the central government and vary by pollutant, but not by industry.

For each polluter, the potential levy (L_j) is calculated for each pollutant; the actual levy is the greatest of the potential levies.[10] This approach obviously differs from a Pigovian system that would charge for each unit of each pollutant. However, each enterprise still faces a complete set of "virtual" charges in each period. To respond appropriately, a cost-sensitive firm must still consider all pollutant charge standards (R_j), payment thresholds (T_j), process pollutant intensities, and abatement cost functions. The firm's economic problem is to adjust its production processes and end-of-pipe waste treatment (and, as a result, emissions of all pollutants) so that, at the margin, the maximum levy for a single pollutant is equal to the sum of abatement costs for all

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[9] Since 1993, the standard fee for wastewater discharges has been 0.05 yuan per ton. Within-standard charges have been assessed on SO_2 emissions since 1996. In effect, China's new pollution levy functions as a two-tier pollution charge system, with uniform rates for within-standard emissions and escalating rates for above-standard emissions. Therefore, unlike its North American counterparts, the Chinese system explicitly incorporates the principle of marginal deterrence [33]. See CRAES [4], SEPA [30] and Bolm et al. [3].

[10] To illustrate, we compute COD and TSS levies for a plant whose waste stream concentrations are 290 $\mu g/m^3$ for COD (local standard = 100 $\mu g/m^3$) and 500 $\mu g/m^3$ for TSS (local standard = 150). The relevant ratios D (percent deviation from standard) are 1.9 for COD and 2.33 for TSS. The plant's annual discharge of wastewater (W) is 2 million tons. Therefore, $P_{COD} = D_{COD} {}^* W = 3{,}800{,}000$; $P_{TSS} = D_{TSS} {}^* W = 4{,}670{,}000$. The charge factors for the two pollutants are $R_{1COD} = \$0.006$/ton; $R_{2COD} = \$0.022$/ton; $R_{1TSS} = \$0.0012$/ton; $R_{2TSS} = \$0.0037$/ton. Fixed payment factors are $L_{0COD} = \$317$; $L_{0TSS} = \$1951$. Applying the elements of formula (1), the total levies are $L_{COD} = \$23{,}117$; $L_{TSS} = \$7555$. Since the levy for COD is higher, the plant's water levy charge is \$23,117.

pollutants. In contrast, the Pigovian problem is, at the margin, to adjust production, waste treatment and emissions to equate the sum of all pollutant charges to the sum of abatement costs for all pollutants. The difference between the Chinese and Pigovian problems depends on the "jointness" of pollutant emissions across process/waste treatment options in a plant: solutions will be similar when emissions are highly correlated across pollutants.

To encourage pollution reduction, levy charges increase with the duration of non-compliance. After 2 years of paying the levy, polluters are subject to an annual 5% increase in the charge rate. The real effect has been minimal to date, however, since China's inflation rate has varied from 2% to more than 10% since 1990. The system also has a "new source bias," since the official charge rate is doubled for facilities that have begun operation since 1979.[11]

The levy formula for air pollution is

$$L_{ij} = \mathrm{Max}[0, R_j V_i (C_{ij} - C_{sj})], \tag{2}$$

where, for facility i and pollutant j, R_j is the charge rate for pollutant j, V_i the total volume of air emission, C_{ij} the pollutant concentration, C_{sj} the concentration standard, L_{ij} the total levy.

Unlike the water levy, the air levy is assessed on the absolute, rather than percentage, deviation from the concentration standard. Again, a firm is assessed only the highest of its potential levies.

2.4. Self-reporting, verification and collection

The levy system is based on universal self-reporting, with verification and collection of levies by local (municipal and county) environmental authorities. All polluters are required to register with local environmental authorities, and to provide information in the following categories: (1) basic economic information (sector, major products and raw materials); (2) production process diagrams; (3) volume of water use and wastewater discharge; pollutant concentrations in wastewater; (4) waste gas volume and air pollutant concentrations (before and after treatment); (5) noise pollution by source; and (6) discharge of solid wastes.

The local environmental authorities check polluters' reports in several ways, including internal consistency; consistency with material balance models; historical data from the facility; direct monitoring; and surprise inspections. When the data are cleared by the environmental authorities, they are used for assessments computed from the levy calculation manual. Firms pay penalties for false reporting and/or non-cooperation with government inspections. Polluters have a 20-day grace period to pay the monthly/quarterly levy, after which the required payment increases by 0.1% per day. Intractable disputes are resolved by the local courts or higher-level environmental authorities.[12] Polluters are required to report increased discharges, and rebates are possible when pollution reductions are verified.

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[11] In our econometric analysis, we find no significant impact for this provision. See the discussion in Section 4.1.

[12] Contested enforcement has very limited relevance in China, because recourse to the local courts is rare. In the US, by contrast, Nowell and Shogren [26] quote EPA Administrator William Reilly as saying, "Four out of every five decisions I make are contested in court."

2.5. Regional variations in the effective levy

In Eqs. (1) and (2), concentration standards are set jointly by local and national regulators, while pollutant levy rates (R) and threshold parameters (T) are formally established by national regulators. Therefore, even within the context of the formulas, local levies can vary for otherwise-identical industries and pollutants. In addition, the levy can be reduced or even eliminated at the discretion of local regulators after appropriate inspections. As a result, effective levy rates vary significantly across Chinese provinces [37]. Although this variation has been criticized as a weakness of the levy system [4], recent research has suggested that its pattern is roughly consistent with the tenets of environmental economics: In general, regulation is stricter in areas where incomes are higher, access to information is better, and pollution is heavier. At the provincial level, Wang and Wheeler [37] 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.

2.6. Use of levy funds

Although the levy's design provides marginal deterrence, the disposition of levy funds has traditionally given the system a pronounced "deposit/refund" character. For individual polluters before 1995, up to 80% of cumulative levy payments were rebatable as cost recovery for documented pollution abatement investments. Since 1995, some areas have converted the rebates to loans in order to sharpen the deterrent effect of the levy. The remaining 20% of levy funds, plus all relevant penalties, can be used by local governments to finance environmental cleanup projects, as well as development and operation of local environmental institutions. The latter provision has provided a strong incentive for local environmental authorities to collect the levies, and has significantly enhanced their institutional capabilities. Table 2 provides information about the use of levy funds from 1992 to 1997. In 1997, the local environmental authorities spent about 40% of the total.

Table 2
The use of pollution levy (unit: 10^4 RMB yuan)

Year	Total	Rebates to polluters	Loans to polluters	Cleanup projects	Institutional development and operation
1992	196,622	118,627		9675	68,320
1993	212,829	120,763		7101	84,965
1994	239,292	115,471		7881	115,940
1995	345,812	103,017	94,157	7192	141,446
1996	431,223	141,823	114,501	9264	165,635
1997	501,200	169,939	126,548	11,752	192,961

Sources: China Environmental Yearbook, 1993–1999.

3. Data and model specification

3.1. Data

This study employs a dataset for 3000 large air and water polluters that has been supplied by China's State Environmental Protection Administration (SEPA) for the year 1993. For each enterprise, the data include the responsible regulatory authority (national, provincial, local), air and water pollutant discharges and abatements, total air and water pollution levies collected, output value, employment, plant ownership, sector, first year of operation, and location. We also use a province-level database, assembled from Chinese Environmental and Statistics Yearbooks, that includes the number of provincial environmental staff, number of industrial pollution sources, number of citizen complaints about pollution, population, industrial output, per capita income, percentage of population receiving secondary education or above, total COD (organic water pollution) discharge and total wastewater discharge. A third database, assembled from provincial and municipal data for 1992, includes measured ambient concentrations of sulfur dioxide and suspended particulate air pollution for the cities in which polluters in the plant-level database are located.

Table 3 provides means and standard deviations for model variables. In the plant-level database, about 93% of the firms are state-owned enterprises; 90% are supervised by central, rather than local, environmental authorities; and 85% are located in regions judged "not environmentally sensitive" for one of two reasons: Some are lightly industrialized or sparsely populated rural areas, where the marginal social damage from pollution is low. Others are areas specifically zoned for heavy industry, where relatively high levels of pollution are permissible under current norms. Most major water polluters are in the chemical, paper and power sectors, while major air polluters are primarily in construction materials, chemicals and smelting.

Table 4 presents the percentile distribution of effective pollution levies, defined as total levies for air and water divided by SO_2- and COD-equivalent total emissions, respectively. The table shows that in a regulatory system based on financial marginal deterrence, simultaneous decisions by firm managers and regulators result in highly varied effective levy rates.[13]

Variables in the regional database highlight the pollution and poverty that remain characteristic of China. For the 50 Chinese cities in which the plants are located, average ambient concentrations are $350\,\mu g/m^3$ for total suspended particulates and $113\,\mu g/m^3$ for SO_2. For the 29 provinces in the regional database, the average discharge concentration of COD (chemical oxygen demand) is $290\,\mu g/m^3$.[14] Average provincial annual income per capita is about 2650 yuan ($320); slightly more than half of the population have received secondary education, and the industry share of GDP is about 40%.

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[13] We cannot compare these composite unit charges to pollutant-specific charges defined by the levy formulas. However, if COD is the only pollutant in a discharge stream, the unit charge may not be too far from the levy formula (0.5 yuan per kg). The same may be true for SO_2, since its formula charge is 0.04 yuan per kg.

[14] The cited concentration levels for air and water pollutants are all at least 5 times higher than levels considered "safe" in the US.

Table 3
Mean values and standard deviations of major variables

Variable and definition	Mean value	Standard deviation	Plants
Water polluters (*1993 data*):			
Value of output (10,000 yuan)	21,976	54,448	1565
Number of workers	4180	20,468	1576
Water levy collected (10,000 yuan)	35	69	1576
Wastewater discharge (10,000 tons)	534	1720	1576
COD discharge (ton)	1611	4271	1576
TSS discharge (ton)	1787	8378	1576
Total COD equivalent water pollution (ton)	3591	10,689	1576
State owned enterprises	93%		1576
Located in environmentally sensitive zone	11%		1576
Central government's supervision	90%		1576
Chemical industry	24.9%		1608
Paper industry	16.4%		1608
Power generation	10.1%		1608
Air polluters (*1993 data*):			
Value of output (10,000 yuan)	26,982	65,000	579
Number of workers	4422	11,000	577
Air levy (10,000 yuan)	16	52	579
Total SO_2 equivalent air pollution (ton)	5240	24,000	579
State owned enterprises	94%		579
Located in environmentally sensitive zone	16%		579
Central government's supervision	94%		579
Construction materials	38.9%		579
Chemical industry	22.6%		579
Smelting	16.2%		579
Regional variables (1992 data)			
			Urban areas
Urban ambient TSP ($\mu g/m^3$)	353	143	50
Urban ambient SO2 ($\mu g/m^3$)	113	77	50
			Provinces
COD discharge concentration ($\mu g/m^3$)	293	165	29
Per capita income (yuan)	2649	707	29
% of secondary education	51.3%	13%	29
Share of industrial GDP	40.1%	6.7%	29
Regulators per firm	1.3	0.5	29
Pollution complaints per 1000 population	0.20	0.08	29

Table 4
Unit charges for polluting emissions (yuan/kg)

Percentiles	COD-equivalent water pollution	SO_2-equivalent air pollution
1%	0.003	0.0006
5%	0.010	0.0023
10%	0.018	0.0048
25%	0.048	0.0187
50%	0.185	0.0535
75%	0.520	0.1832
90%	1.475	1.0464
95%	2.808	2.5995
99%	20.976	37.5417

3.2. *Modeling issues*

As our discussion of its design has suggested, China's pollution levy is based on a clearly defined principle of financial marginal deterrence, with universal self-reporting and little scope for contested enforcement. Given the stringency of Chinese concentration standards, significant marginal abatement costs, and reasonably careful local monitoring by regulators, we would expect this system to induce many cost-sensitive firms to report non-compliance and pay levy charges. Our data are consistent with this expectation: in 1993, among 3000 of the biggest polluters in China, about 90% of water polluters reported violations of the discharge standards and paid the levies. China's water concentration standards are more stringent than its air concentration standards, but over 50% of air polluters also reported violations and paid the levies.

Of course, the fact of payment does not automatically signify deterrence, particular in a state-enterprise-dominated economy like China's. Actual pollution reduction depends on two factors: The "softness" of state enterprise budget constraints, which is hard for outsiders to judge, and the relationship between the marginal levy rate and the marginal cost of abatement. At the micro-level, there has been little relevant evidence until recently about state enterprise responsiveness to the levy.[15] Florig et al. [10] argue that the levy's impact must be insignificant because plants only pay for "illegal" (above-standard) discharges, and because the charges are not significant relative to firms' production costs and pollution abatement costs. Some case studies [34] support this argument by suggesting that levy rates are less than the average cost of abating pollutants at their legal concentration standards. However, these critiques ignore the central importance of *marginal* deterrence in this context: For cost-sensitive firms, the relevant comparisons involve marginal values, rather than absolute or average values.

The central policy question therefore remain unanswered: has the pollution levy had a significant deterrent effect on polluters in China? We address this question with a model of jointly determined enforcement and emissions that is consistent with the major characteristics of the levy system.

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[15] Wang [35] found that the levy had a significant and positive impact on pollution abatement expenditures in China.

3.3. General equation specification

For the ith plant in the kth region, we specify the general form of the levy equations as

$$\mathrm{EL}_{ik} = f_i(\mathrm{EE}_{ik}, \mathrm{EV}_{ik}, \mathrm{EG}_{ik}, \mathrm{EN}_{ik}), \tag{3}$$

where EL is the effective levy rate, EE the pollutant emissions, EV the waste stream volume, EG the vector of local monitoring and enforcement determinants, EN the vector of plant-specific enforcement factors.

Each emissions equation is specified as

$$\mathrm{EE}_{ik} = f(\mathrm{EL}_{ik}, \mathrm{EP}_{ik}, \mathrm{EC}_{ik}, \mathrm{EO}_{ik}), \tag{4}$$

where EP is the vector of other policy variables, EC the vector of abatement cost determinants, EO the enterprise ownership (state vs. private).

For air and water emissions separately, we define the effective levy as the total levy divided by an index of total discharges. The total discharge index accounts for differences in risk-weighted unit pollution charges that are mandated by Chinese regulations. For air pollution, we construct an SO_2-equivalent index as the weighted sum of 22 air pollutant emissions, where the weight for each pollutant is the ratio of its unit levy price (R_j in Eq. (2)) to the unit levy price of SO_2 in the Chinese levy system:

$$\mathrm{AP} = \sum_j \left[\frac{R_j}{R_{\mathrm{SO}_2}}\right] E_j. \tag{5}$$

For water pollution, the index reflects the relative importance of different pollutants in two dimensions mandated by the Chinese levy system: their relative unit prices (R_j) and concentration standards ($C_{\mathrm{s}j}$) in Eq. (1).[16] For 29 water pollutants, we define a COD-equivalent index as

$$\mathrm{WP} = \sum_j \left[\frac{C_{\mathrm{sCOD}}}{C_{\mathrm{s}j}}\right] \left[\frac{R_j}{R_{\mathrm{COD}}}\right] E_j, \tag{6}$$

where C_{s} is the concentration standard.

In the estimating equations, we include the weighted discharge indices (AP,WP) and effective levy measures as endogenous variables. The availability of data on discharge removal at the end-of-pipe also enables us to distinguish between process change and direct pollution control as sources of emissions reduction.

3.4. Effective levy equations

Dependent variables in the effective levy equations are air and water levies collected, divided by the respective weighted pollution discharge measures. Right-hand variables include the instrumented forms of the weighted discharge indices and volumes of wastewater and waste gas, as well as three local enforcement factors (regulators per firm, pollution complaints per capita, and location in an environmentally sensitive zone), one national enforcement factor (central government supervision), and four plant-level variables that may affect negotiations with

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[16] Note that in the Chinese system, the concentration standard enters as a denominator in the water levy formula, but not in the air levy formula.

regulators: state ownership, output/worker (a proxy for financial condition), age (a proxy for "grandfathering" under the levy statute), and number of workers (a proxy for local employment importance).

In our model, the effective levy rate and emissions are jointly determined. However, the formulas in Eqs. (1) and (2) are specified for total levies. To see the implications, we provide a simple transformation of the first part of the effective levy equation:

$$\begin{aligned}
&\log \mathrm{EL}_i = \alpha_0 + \alpha_1 \log \mathrm{EE}_i + \alpha_2 \log \mathrm{EV}_i \\
&\log \mathrm{EE}_i = \log C_i + \log \mathrm{EV}_i \\
&\log \mathrm{EL}_i = \alpha_0 + \alpha_1 \log C_i + (\alpha_1 + \alpha_2) \log \mathrm{EV}_i \\
&\log(\mathrm{TL}_i) = \log \mathrm{EL}_i + \log \mathrm{EE}_i = a_0 + (1 + \alpha_1) \log C_i + (1 + \alpha_1 + \alpha_2) \log \mathrm{EV}_i, \qquad (7)
\end{aligned}$$

where EL is the effective levy rate, TL the total levy collected, EE the total pollutant, EV the waste stream volume, C the pollutant concentration.

Our model incorporates all forms of air and water pollution in unit-equivalent indices, so we have no independent measure of concentration. At the aggregate level, total pollutant is the product of waste stream volume and overall pollutant concentration. In the log–log model, by implication, the marginal effect of overall concentration on the total levy collected is captured by one plus the parameter estimate for weighted pollution discharge, and the marginal effect of waste stream volume is 1 plus the former parameter plus the direct parameter estimate for waste stream volume. We expect both marginal effects to be positive, although we are agnostic about parameter sizes.

The first local enforcement factor is total environmental officers divided by the number of plants in the provincial regulatory system. The local budget for environmental administration is tied specifically to the pollution levy, so we take the precaution of treating this provincial variable as endogenous, even though our analysis is at the micro-level. We would expect local monitoring and enforcement capability to have a positive effect on levy collections. The second local enforcement factor, an index of public support for environmental enforcement, is the incidence of pollution complaints sent to regulators. Dasgupta and Wheeler [7] have shown that pollution complaints are strongly affected by local environmental conditions and development levels. We treat this variable as exogenous, because our micro-level observations are far removed from the full range of province-level pollution problems that prompt complaints (e.g. sewage, trash-burning, motor vehicle exhaust). We would expect the effective levy to increase with the incidence of pollution complaints. The third factor is a dummy variable for zones identified as environmentally sensitive by regulators. Ceteris paribus, we would expect the pollution levy to be higher in such zones. Age is also a potential enforcement factor since, as we have previously noted, the official charge rate is doubled for newer facilities.

We also include a national enforcement factor—a dummy variable that indicates whether the plant is on the national pollution control priority list, and monitored and managed by a national-level environmental agency. The impact of this variable on the pollution levy could be negative, since local environmental authorities may have less power to collect levies from plants that are not under their immediate jurisdiction.

We include three plant-level variables as possible determinants of negotiations between regulators and plant managers: state ownership, number of employees, and output per worker.

The first two are also determinants of emissions in our model, so we interpret results for these variables as residual effects attributable to negotiation. Empirical research conducted in Zhenjiang, a city in China, shows that firms which are privately owned have less bargaining power in levy payment and that a bad financial situation entails a higher relative bargaining power and a bigger effort to bargain for less levy payment [36]. For this reason, we would expect state ownership to be associated with lower levies and effective levies to be higher for plants with more output per worker. We treat output per worker as an endogenous variable, since it can be directly affected by levy payments as well as abatement costs associated with emissions reduction. The impact of plant-level employment is ambiguous. Large plants may attract more regulatory attention because the impact of their discharges on neighboring communities may be substantial. On the other hand, such plants may be given favorable treatment because they are important sources of local employment.

3.5. Emissions equations

We model emissions as a function of the (endogenous) effective levy rate, other policy variables, determinants of abatement cost, and ownership. We fit one set of equations to the weighted discharge indices for water and air. In the other set, we test for separate effects on production processes and at the end-of-pipe.[17] For the second set, we use data for two water pollutants (chemical oxygen demand (COD), total suspended solids (TSS)) and two air pollutants (flue dust, SO_2).

Our plant-level data report levies paid, but do not provide information on subsequent rebates for pollution control investments. Our computed effective levy rate is the penalty actually paid, not the charge net of subsequent rebates. Faced with a marginal deterrent that can rise to very pronounced levels (see Table 4), even state enterprise managers should respond to this marginal deterrent unless they can run deficits with complete impunity. We have no reason to believe that individual state enterprises have such extreme flexibility in China. The system for use of levy funds (described in Section 2.6) provides another reason for us to expect an elastic response. The fund disbursement system treats up to 80% of a firm's cumulative levy payments as a "deposit" that can be rebated for future abatement projects. Although the available data do not permit us to assess the relative size of levy payments and abatement costs, this rebate policy undoubtedly lowers the expected cost of abatement at least somewhat. At the same time, investment in process or end-of-pipe pollution reduction lowers the present discounted cost of future levy payments. So, the rebate system should raise the expected net benefits of pollution control investments and increase the firm's responsiveness to the levy.[18]

We include two policy variables besides the effective levy rate, both of which should have negative effects on emissions (ceteris paribus). The first, location in an environmentally sensitive zone, should be associated with more restrictive discharge standards. The second, national regulatory oversight, should reflect more restrictive executive orders from government authorities.

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[17] By definition, plant emissions equal process pollution discharges minus end-of-pipe removal.

[18] We are indebted to an anonymous reviewer for calling our attention to the response-enhancing character of the rebate system.

We include four plant-level variables: state ownership, employment size, age and industry sector. Previous empirical work has suggested that management inefficiency in state-owned plants leads to generation of more waste residuals, so we would expect state ownership to have a positive impact on emissions, ceteris paribus [6]. The other three variables are determinants of abatement costs. Employment size proxies abatement scale economies: we would expect emissions to increase more slowly than employment, ceteris paribus [16,17]. Plants with older equipment should have higher abatement costs, although we recognize that our proxy variable (startup date) does not fully capture this effect. Because industry sectors exhibit wide variations in determinants of abatement costs (material inputs, process technologies, etc.), we also include sector controls.

4. Estimation results

We estimate all equations by two-stage least squares, with standard corrections for heteroskedasticity. We treat effective levies, emissions, regulators per plant and output per worker as endogenous variables, using a large set of regional- and plant-level exogenous variables as instruments.[19] Log forms are used for all continuous variables in the estimation.

Since we cannot construct the effective levy for plants that do not pay levies, we have decided not to include them in the analysis. Our reasoning is as follows: In the Chinese system of financial marginal deterrence, a firm's stance on compliance is an economic, not a legal, decision. In a system where 90% of water polluters and 50% of air polluters are non-compliant, we know that the effective levy rate faced by totally compliant firms must be quite high (otherwise, they would choose some degree of non-compliance). But, aside from the information yielded by our econometric model, we have no way of simulating the effective rate faced by such firms. If we used our econometric results to simulate the effective rate for totally compliant firms, thereby expanding the estimation "sample", we would actually be engaging in an econometric sleight-of-hand—expanding the nominal degrees of freedom in the system but adding no new information about the levy. To keep the exposition clear and straightforward, we have decided not to take this approach.

4.1. Effective levy equations

We report results for effective water and air levies in Table 5. Both equations are fitted to large samples (1237 and 576 plants, respectively), and both have relatively high levels of explained variance (adjusted R^2's of 0.60 and 0.54, respectively). Overall, the results are strongly consistent with increasing deterrence, with greater impact for waste stream volume than pollutant concentration. Some local and national enforcement factors are significant, but factory-specific negotiation factors have no consistent effect on effective levies.

Our results suggest that pollution levies respond significantly, but with relatively low elasticities, to changes in overall pollutant concentration. When one is added to the parameter estimates, the

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[19] Besides the exogenous variables included in the model, we use local ambient air quality and provincial water pollution discharges, income and education.

Table 5
Estimation results for air and water pollution levies

	Water	Air
	Log (Charge per unit of water pollution)	Log (Charge per unit of air pollution)
Log (COD equivalent total water pollutants discharged)[a]	−0.799***	
	(−10.8)	
Log (total volume of wastewater discharge)[a]	0.360***	
	(4.247)	
Log (SO_2 equivalent total air pollutants emitted)[a]		−0.940***
		(−7.343)
Log (total volume of waste gas emission)[a]		0.805***
		(8.236)
Log (regulators per firm)[a]	0.282***	0.445**
	(3.01)	(2.477)
Log (Complaints/1000 population)	0.228**	0.173
	(2.277)	(1.081)
State ownership	0.170	−0.516**
	(1.263)	(−2.208)
Log (age)	−0.123	0.447***
	(−1.359)	(3.285)
Log (Number of workers)	0.395***	−0.263**
	(11.69)	(−2.508)
Log (Output/worker)[a]	0.656***	−0.092
	(6.69)	(−0.736)
Under central government's supervision	−0.311***	−0.306
	(−2.809)	(−1.133)
Located in environmentally sensitive zone	−0.120	0.270*
	(1.220)	(1.795)
Constant	−3.58***	−5.89***
	(−7.257)	(−7.19)
R^2	0.603	0.539
N	1237	576

Note: *t*-values are provided in the parentheses. ***Classical significance at 99% confidence; ** 95%; *90%.

[a] Variable instrumented.

implied elasticities are 0.20 for water and 0.06 for air, respectively.[20] The response elasticities are considerably higher for waste stream volumes: When one is added to the sum of the pollutant and waste stream elasticities, the implied elasticities are 0.56 for water and 0.87 for air.[21] Since overall

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[20] In this context, see the discussion of Eq. (7).

[21] Again, see the discussion of Eq. (7).

pollution is log-additive in waste stream volume and pollution concentration, the combined elasticities (0.76 and 0.93, respectively) suggest that the air and water levies rise somewhat less than proportionately with pollution. In addition, they suggest that Chinese regulators focus more strongly on waste stream volume than pollutant concentration.

The signs and significance of three local and national enforcement variables are generally consistent with prior expectations. Both air and water levies increase significantly with increases in local regulators per plant. A higher incidence of pollution complaints is also associated with higher levies, although only water exhibits high significance. Central government supervision seems to impede local levy collection, but again, the effect is highly significant only for water. Location in an environmentally sensitive zone and age both have a significant positive effect for air pollution levy but are not significant for water.

State ownership has a significant, negative correlation with the effective levy on air pollution, which is consistent with expectation and previous research, but is not significant for water pollution. Output per worker has a significant, positive correlation with the effective levy on water pollution, which is consistent with expectation and previous research, but is not significant for air pollution. The number of workers has significant, contradictory results between air and water pollution levies. This variable may correlate with both the abatement cost and the bargaining power of a factory for levy payment.

4.2. Emissions equations

We report results for the emissions equations in Tables 6 and 7. The two most general equations, for total weighted emissions, suggest a strong marginal deterrent effect for the effective levies. Separation into process and end-of-pipe effects suggests that the locus of enterprise response to the levy is process change, not increased end-of-pipe removal. Among the right-hand variables, other policy variables have no consistent, significant effect. However, the results for abatement cost determinants are strong and consistent with our prior expectations.

The weighted emissions equations (first columns, Tables 6 and 7) suggest a strong marginal deterrence effect for the pollution levy. The highly significant estimated elasticity (−1.08) for water pollution implies that emissions decline by about 1% for each 1% increase in the effective levy rate. For air pollution, the estimated elasticity of −0.65 (also highly significant) implies that emissions decline by about 0.65% for each 1% increase in the effective levy rate. For SO_2 emissions alone, the estimated elasticity is −1.03 and highly significant.

Our process and end-of-pipe results suggest that firms' response to the water pollution levy is heavily focused on process change, rather than end-of-pipe removal. For both COD and TSS, the estimated process response elasticities are −0.74 and −0.66, respectively, and both are highly significant. In contrast, the (insignificant) elasticities for end-of-pipe removal are −0.10 and 0.26, respectively.[22] We have no equivalent decomposition in the data for SO_2, although its overall response to the effective levy rate is highly significant. When we treat flue dust separately, we obtain relatively low, statistically insignificant responses to the effective levy rate at both the process and end-of-pipe levels.

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[22] Since levies are rebated for pollution control investments, one apparent implication of this result is that "upstream" process investments with documented pollution reduction effects represent acceptable uses of levy funds.

Table 6
Estimation results for water emissions

	Log (COD equivalent total water pollution)	Log (COD generated)	Log (COD removed)	Log (TSS generated)	Log (TSS removed)
Log (Charge per unit of water pollution)[a]	-1.08^{***}	-0.741^{***}	-0.095	-0.664^{**}	0.261
	(-5.343)	(-2.978)	(-0.279)	(-2.208)	(0.539)
Located in environmentally sensitive zone	-0.290^{***}	-0.044	0.054	0.108	0.329
	(-2.654)	(-0.289)	(0.166)	(0.524)	(0.921)
Under central government's supervision	-0.239^{**}	-0.099	0.116	-0.156	0.551
	(-2.140)	(-0.653)	(0.382)	(-0.685)	(1.103)
State ownership	-0.073	-0.103	-0.068	-0.007	0.446
	(-0.479)	(-0.616)	(-0.243)	(-0.034)	(1.074)
Log (age)	0.101	0.101	-0.132	0.006	0.115
	(0.676)	(0.484)	(-0.367)	(0.025)	(0.408)
Log (number of workers)	0.727^{***}	0.730^{***}	0.571^{***}	0.900^{***}	0.728^{***}
	(16.768)	(11.398)	(3.900)	(12.358)	(4.284)
Sectoral dummy variables					
Food	1.03^{***}	1.296^{***}	0.487	0.100	-1.296^{*}
	(4.990)	(3.961)	(0.756)	(0.301)	(-1.725)
Textiles	-0.421^{*}	-0.367	-1.205^{**}	-1.535^{***}	-2.972^{***}
	(-1.798)	(-0.931)	(-1.981)	(-3.891)	(-4.146)
Leather	0.162	0.293	-0.820	-0.591	-2.046^{***}
	(0.516)	(0.758)	(-0.991)	(-1.498)	(-3.019)
Paper	0.774^{***}	0.900^{***}	0.180	0.522^{*}	-0.142
	(3.316)	(3.373)	(0.361)	(1.672)	(-0.278)
Petroleum	0.750^{***}	-0.035	-0.639	-1.917^{***}	-1.616
	(3.146)	(-0.081)	(-0.911)	(-4.362)	(-1.129)
Chemicals	0.554^{***}	-0.576^{**}	-1.280^{**}	-0.614^{**}	-0.935^{*}
	(4.263)	(-2.065)	(-2.195)	(-2.326)	(-1.902)
Pharmaceuticals	0.975^{***}	1.109^{***}	-0.540	-1.360^{***}	-2.629^{***}
	(4.552)	(3.123)	(-0.721)	(-3.556)	(-2.813)
Fiber	1.046^{***}	0.924^{**}	-0.156	-0.341	-2.465^{***}
	(4.752)	(2.552)	(-0.721)	(-0.936)	(-3.706)
Rubber	-0.977	-2.111^{***}	-2.170^{**}	0.303	-0.534
	(-1.479)	(-3.088)	(-2.658)	(0.391)	(-0.487)
Plastics	-0.644^{**}	-0.956^{***}	-1.042^{**}	-1.900^{***}	
	(-2.255)	(-3.238)	(-1.925)	(-4.819)	
Smelting	0.323	-1.378^{***}	-1.561^{**}	-0.295	-0.452
	(1.633)	(-3.556)	(-1.997)	(-0.704)	(-0.583)
Equipment	-1.211^{***}	-2.352^{***}	-5.509^{***}	-3.156^{***}	-6.131^{***}
	(-4.623)	(-5.657)	(-6.568)	(-7.601)	(-5.407)

Table 6 (*continued*)

	Log (COD equivalent total water pollution)	Log (COD generated)	Log (COD removed)	Log (TSS generated)	Log (TSS removed)
Electronics	−0.793	−1.852**		−1.620*	
	(−1.343)	(−2.337)		(−1.746)	
Power	0.569*	−0.947*	−1.305	0.943	0.966
	(1.851)	(−1.919)	(−1.605)	(1.595)	(0.989)
Metal	−0.776**	−2.228***	−4.513***	−3.90***	
	(−2.020)	(−3.488)	(−8.140)	(−4.346)	
Construction materials	−1.321***	−2.592***	−3.919***	−1.435***	−3.736***
	(−3.748)	(−5.158)	(−4.004)	(−2.712)	(−3.509)
Printing	0.443	−1.092**		−2.394***	
	(1.208)	(−2.423)		(−4.615)	
Constant	−3.993***	−2.449	2.350	−2.714	1.753
	(−3.477)	(−1.364)	(0.814)	(−1.419)	(0.615)
R^2	0.59	0.49	0.32	0.330	0.24
N	1514	1167	414	1126	445

Note: t-values are given above in the parentheses. ***Notes for classical significance at 99% confidence; **95%; *90%.
^{a}Means that variables are instrumented.

The results reported in the previous section suggest that local and national enforcement factors significantly affect emissions through their impact on the pollution levy. However, the results in Tables 6 and 7 are not consistent with any remaining, direct effect. For both location in an environmentally sensitive zone and central government supervision, the pattern of signs and significance is essentially random.[23]

In contrast to the findings of previous econometric work, we find no significance for state ownership in the determination of plant-level emissions. We find no significance for plant age, although the result may be affected by our use of startup date as a weak proxy. However, the other two determinants of abatement cost have large, significant effects. Using employment as a proxy for plant scale, we find emissions elasticities consistently in the range 0.5–0.7 (TSS generation is higher, at 0.90), indicating that marginal abatement costs are lower for larger plants. This result agrees with the findings of several previous studies of plant scale and pollution in Asian and Latin American countries [5,14,27]. We find strong sector effects in all the equations, reflecting the impact on abatement costs of differences in material inputs and process technologies.

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[23] We recognize the possible endogeneity of emissions volume and selection for the national pollution control priority list. Positive, significant results might have been generated by some upward bias in estimated parameter values. However, we find no consistent pattern of signs or significance in any case.

Table 7
Estimation results for air emissions

	Log (SO_2 equivalent total air pollution)	Log (Dust generated)	Log (Dust removed)	Log (SO_2 emissions)
Log (Charge per unit of air pollution)[a]	−0.647***	−0.257	−0.281	−1.027**
	(−2.863)	(−0.472)	(−0.507)	(−2.409)
Located in environmentally sensitive zone	0.186	1.191**	1.328**	0.020
	(1.567)	(2.473)	(2.390)	(0.089)
Under central government's supervision	−0.133	0.821**	1.347***	−0.082
	(−0.634)	(2.173)	(3.290)	(−0.247)
State ownership	0.0179	0.813	1.114	−0.246
	(0.093)	(1.424)	(1.623)	(−0.743)
Log (age)	0.105	−0.285	−0.348	0.227
	(0.945)	(−1.035)	(−1.160)	(1.536)
Log (Number of workers)	0.643***	0.660**	0.633**	0.475**
	(5.453)	(2.441)	(1.994)	(2.410)
Sectoral dummy variables				
Mining	2.160***	−1.839	5.251***	0.411
	(3.329)	(−0.851)	(4.323)	(0.662)
Steam water supply	3.807***	−3.487**	4.292***	1.580***
	(10.819)	(−2.432)	(4.973)	(3.202)
Food	1.766***			−0.725
	(7.553)			(−0.625)
Textiles		−9.085***	−1.684	−1.702
		(−12.292)	(−1.250)	(−1.556)
Leather	1.073*	−5.416***	2.257*	−0.694
	(1.861)	(−3.173)	(1.670)	(−0.630)
Paper	2.592***	−3.988**	3.531***	1.047**
	(6.065)	(−2.316)	(2.933)	(2.441)
Petroleum	1.635***	−4.785**	2.469***	−0.596
	(3.651)	(−2.482)	(4.928)	(−1.050)
Chemicals	1.831***	−3.691***	4.121***	−0.569
	(7.374)	(−2.787)	(4.611)	(−0.787)
Pharmaceuticals	1.485**	−8.638***	−0.716	0.375
	(2.547)	(−6.402)	(−0.900)	(0.928)
Fiber	2.135***	−2.591	6.116**	−0.276
	(5.090)	(−0.855)	(2.013)	(−0.416)
Rubber	1.543***	−7.806***	0.170	0.149
	(2.605)	(−4.035)	(0.334)	(0.250)
Plastics	1.358**			
	(2.466)			
Smelting	2.622***	−1.670	6.208***	0.472
	(5.226)	(−0.858)	(16.155)	(1.143)
Equipment	0.759**	−5.825***	2.129***	−1.208**
	(2.035)	(−3.822)	(2.625)	(−2.271)

Table 7 (*continued*)

	Log (SO_2 equivalent total air pollution)	Log (Dust generated)	Log (Dust removed)	Log (SO_2 emissions)
Power	3.028^{***}		7.160	0.370
	(7.129)		(3.521)	(0.202)
Metal	−0.543	-7.902^{***}		-2.587^{***}
	(−1.069)	(−4.007)		(−7.301)
Construction materials	-1.321^{***}	−0.810	6.901^{***}	0.304
	(−3.748)	(−0.858)	(15.348)	(0.860)
Constant	-3.669^{***}	−2.449	-14.319^{***}	-3.534^{***}
	(−3.339)	(−1.364)	(−8.132)	(−3.106)
R^2	0.71	0.28	0.27	0.29
N	577	435	396	549

Note: t-values are given in the parentheses. ***Notes for classical significance at 99% confidence; **95%; *90%.

[a] Means that variables are instrumented.

5. Summary and conclusions

China's pollution regulation system provides an interesting counterpoint to North American systems for an analysis of enforcement and deterrence. While the US and Canadian systems have traditionally relied on legal sanctions for non-compliance, China's pollution levy regulations call for financial charges that escalate with the degree of non-compliance. Financial marginal deterrence in the Chinese system is coupled with two other features that differentiate it from North American systems: Universal self-reporting, and the effective absence of legal options for contesting administrative decisions by regulators. In addition, China's system operates in what remains a very poor country, with wide regional disparities in economic development, institutional capability and environmental quality.

The levy makes compliance an economic decision in China, rather than the legal decision that confronts North American firms. China's pollution levy therefore provides a case of explicitly endogenous enforcement, in which the pollution levy rate and emissions are jointly determined at the factory level. Using data from 3000 Chinese factories, we estimate an econometric model that incorporates this endogeneity. In the model, factories' levy rates and emissions are jointly determined by the interaction of local and national enforcement factors, abatement costs and, at least potentially, regulator-manager negotiations that are sensitive to plant characteristics.

Our results demonstrate the significant deterrent impact of a system that combines progressive financial penalties and self-reporting with few options for contesting regulatory decisions. The strength of the results is reinforced by the countervailing absence of hard budget constraints in at least some of the state-owned firms that dominate our sample, as well as the fact that China remains a developing country with significant institutional weaknesses. Our results also shed light on other questions that are of general interest in this context. First, our results are consistent with other studies of regional variations in enforcement. Despite central pressure for uniformity in enforcement, we find a strong reflection of China's regional variation in local enforcement practices. Effective pollution levies are higher in areas where regulatory institutions are stronger.

The levies are also raised by a higher incidence of local pollution complaints, which in turn reflect local levels of education and environmental quality. Second, our results suggest potential regulator–manager negotiations based on plant characteristics such as ownership and financial viability, even though the results are not supported by both the air and the water pollution levy equations. Finally, our detailed Chinese data have enabled us to assess the impact of financial incentives on pollution reduction at two levels: the production process, and end-of-pipe abatement. Our results strongly suggest that the dominant impact of financial incentives for pollution control is ‘‘upstream’’, through adjustments in the production process itself.

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