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Assessment of China's pollution levy system: an equilibrium pollution approach

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ABSTRACT There is considerable concern about the effectiveness of China's pollution control policies. Despite government intervention, measures of pollution continue to rise. However, this does not mean that policies have necessarily been ineffective. What matters for the effectiveness of policy is not the overall level of pollution but whether the extent of pollution is improving relative to what it otherwise would have been without a policy intervention. This paper assesses the effectiveness of China's pollution levy system on water pollution, air pollution, and solid wastes using econometric techniques to estimate the effectiveness of government intervention. The paper first sets out a theoretical equilibrium model of pollution and then uses this to derive equations for the demand and supply of pollutants. This theoretical framework is then used to develop an econometrically estimated model. We find that it is possible to estimate a well-defined demand function for pollution (a reduction in environmental quality) but are unable to estimate the supply of environmental goods, suggesting that government regulation rather than consumer preferences are determining the rate of environmental degradation in China. We also find that the pollution levy system has been effective in reducing pollution relative to what it otherwise would have been in China.

1 Introduction

There is considerable concern about the effectiveness of China's pollution control policies especially when various measures of pollution emissions continue to rise. However, looking at overall pollution does not necessarily give a good indication of the effectiveness of pollution abatement policy because there are a number of factors causing pollution to rise which are independent of the policies being undertaken. A more accurate assessment of the effectiveness of pollution control policies is whether the extent of

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pollution is improving relative to what it otherwise would have been without policy intervention. In the case of China, this is particularly important because in a rapidly growing economy with low levels of income per capita, pollution would be expected to increase (see, for example, Grossman and Krueger, 1995).[1] In this paper we attempt to quantify the effectiveness of pollution control measures in China using an econometric approach which attempts to measure the extent of abatement relative to pollution that would have occurred without the pollution control policy. We also attempt to draw inferences on the efficiency of the Chinese pollution control policies.

China's pollution levy system dates from the late 1970s. Clause 15 of China's Environmental Protection Law (Provisional) promulgated in 1979 specifies that 'in case where the discharge of pollutants exceeds the limit set by the state, a pollution levy shall be charged according to the quantities and concentration of pollutants released'.[2] Shortly after the passage of this law, a few regions began experimental collection of the pollution levy. In 1982, China's State Council issued the 'Provisional Regulations for Collection of Compensation Fees for Pollutant Discharge', marking the nationwide implementation of this system. After that, the regulations have been amended several times. The National Environmental Protection Agency (NEPA) revised the levy rate and calculation method in 1991.[3] Originally, only over-standard discharge of wastewater, waste gas, and solid wastes were subject to the levy. Since 1991, noise sources have been liable for the levy. Several regions have experimentally collected fees for SO_2 discharged from industrial coal burning since 1992. In addition to the over-standard fees, Clause 15 of China's Water Pollution Prevention and Control Act made in 1984 stipulates that the total amount of wastewater is also subject to the pollution levy. Since then, several regions formulated their own regulations regarding the collection of the wastewater fee. It became a nationwide practice when the State put in place a unified regulation about the wastewater fee in 1993. Almost all of China's counties and cities have now implemented the levy system. Approximately 500,000 factories have been charged for their emissions, and more than 4 billion RMB Yuan of levies have been collected (NEPA, 1997). About 80 per cent of the funds collected, have been used to finance industrial pollution prevention and control, accounting for about 15 per cent of total investment in these activities (NEPA, 1994).

[1] Recent studies, for example, Dinda, Coondoo, and Pal (2000), show that the environmental Kuznets curve may in fact be downward sloping for some pollutants in a broad range of per capita income, i.e. from 0 to more than US$8000. However, a closer observation of the lower end of per capita income, probably less than US$1000 where China lies, may still reveal a positive relationship between pollution and income (Dinda, Coondoo, and Pal, 2000, figure 1).

[2] The formal China's Environmental Protection Law promulgated in 1989 specifies similar requirements in Clause 28.

[3] In 1998, NEPA was restructured as the State Environmental Protection Administration (SEPA) with ministry authority in the central government, signaling China's serious concern about environmental issues.

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China's pollution levy system has its peculiar characteristics. To determine the amount to be collected, the government sets an emission standard for the firm and the firm is subject to an emission levy if its emission violates the standard.[4] The system uses a 'markup' based on the percentage deviations from the discharge standards for effluent concentrations. Usually the levy is the product of this 'markup' and the excess emissions. This is quite different from a tax on specific pollutants. In fact the pollution levy can be characterized as a one-sided hybrid policy. If one source discharges multiple pollutants, levies are charged only on the 'worst case' pollutant, that is pollutant incurring the highest levy liability, from each source. As 'worst case' pollutants are successively cleaned up, the levy will shift across pollutants.

The revenue from the levy is earmarked for environmental protection. Notionally 80 per cent of the fee is returned to the contributing enterprise in some regions. Because the fee is treated as a production cost and is tax deductable, firms are willing to pay the fees just as a means of reducing their tax liability. This practice has therefore been heavily criticized. The authorities have also used the revenue to collectively subsidize some 'important' projects, and gradually turn the subsidy into a loan, although it is exempt of repayment in certain circumstances.

This system has received a number of other criticisms. For example, the standard was only set on the concentration of a pollutant and thus firms may simply dilute their emissions to meet the standard in the case of wastewater. In order to tackle the problem of dilution of emissions, charges based directly on the quantity of emission have been introduced. Some also argue that the levy rate is too low to give incentives for firms to comply with the environmental regulation. Thus, from some critics' point of view, the levy is merely a local financing mechanism which is ineffective as a regulation instrument. Moreover, the strictness of enforcement is thought to vary widely, so factories in different regions face very different penalties for polluting (Qu, 1991; NEPA, 1994; Shibli and Markandya, 1995; Wang and Lu, 1997).[5]

Despite the above criticisms of the pollution control measures in China, a series of papers by World Bank staff show that the pollution levy system has played an important role in preventing China's water environment from further deterioration. Using firm-level data, Dasgupta *et al*. (1996) find that the current pollution levy system provides an economic incentive to abate. However, their results also suggest that changing to a full

[4] It is not an offence to discharge pollutants exceeding the limit set by standards. NEPA regulations specify variations in effluent standards by sector and fees by pollutant. With the approval of NEPA, local authorities may raise both standards and fees above the nationally mandated level.

[5] Responding to these critiques, NEPA has been reforming the system in four directions: moving from pollution levy only for over-standard emissions to levy for total amount of emissions; moving from charging the 'worst case' to pollution levy based on multiple pollutants; moving from pollution levy based on only concentration standard to on both concentration and quantity; moving from static to dynamic.

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emissions charge system would greatly reduce the overall abatement costs. Based on an equilibrium pollution theory, an econometric analysis by Wang and Wheeler (1996) finds that the water pollution levy system is neither arbitrary nor ineffective. Across provinces and over time, variations in the effective levy rate are well explained by proxies for local valuation of environmental damage and community capacity to enforce local norms. But their findings cannot be extended to the area of air pollution control without further analysis. Moreover, the environmental supplies are concurrently determined for all elements, therefore findings may be biased if only wastewater is considered.

This paper attempts to examine the effectiveness and efficiency of China's pollution levy system in a quantitative way. It is organized as follows. The next section introduces a theory of equilibrium pollution in order to give an analytical base to the econometric testing. Using the theoretical framework, supply and demand of environmental goods are derived in section 3. Section 4 describes the data used for estimation. The estimation results are presented and discussed in section 5. Finally concluding remarks are provided in section 6.

2 A theory of equilibrium pollution

In this section we present a simple model of equilibrium pollution. Some discussion of terminology is helpful before we start. We assume that pollution and environmental goods are inverses of each other. In other words when firms pollute they run down the stock of environmental goods. The more pollution—the less environmental goods. Thus we define environmental demand as the demand by firms for the right to pollute. Environmental supply is the supply of environmental goods that households are willing to provide (that is, they are willing to give up some clean environment). An increase in pollution is a reduction in the environmental good. The household in the model should be understood as a combination of the usual household and the government. As the government aims to maximize the utility of the household which is affected by the environmental quality, this treatment is equivalent to a more decentralized case where household and government are separated.[6]

Environmental demand (the demand by firms to pollute)

A representative firm is assumed to maximize its profits. The firm employs capital, labor, and an environmental good to produce its products

$$q = f(K,L,E) \tag{1}$$

where q is the product amount, K is the capital input, L is labor input, and E is a set of environmental inputs (pollutant emissions).

Normalizing by the product price, the firm's problem is

$$\begin{aligned} Max_{K,L,E} \quad & f(K,L,E) - (rK + wL + p_e E) \\ s.t. \quad & E \leqslant E_s \end{aligned} \tag{2}$$

[6] A Proof of the equivalence can be obtained from the authors.

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where r, w, and p_e are respectively cost of capital, wage rate, and the effective pollution emission levy rate. This approach is different from the usual one in the treatment of pollution abatement costs. Most of the literature assumes minimization of abatement costs and pollution levy or tax (for example, Wang and Wheeler, 1996; Xie, 1996). However, it is often difficult to distinguish 'normal' production activities and pollution abatement activities, even from an engineer's point of view. The abatement activity also employs capital and labor, therefore it could be included in the 'normal' production process like equation (1). We assume that the pollution abatement cost and levy/tax minimization may omit the possibility of substitution between production activities and abatement activities. Moreover, this kind of treatment reduces data requirements. The usual approach needs disaggregated cost accounts and more technical data, like influent and effluent concentrations and amounts, which are not available in most cases.[7] Another distinguishing feature of problem (2) is the constraint on pollution emissions. This constraint, although not specifically set in the real world, comes from regulation requirements. It is understandable that firms face stringent environmental requirements in regions where the regulations are strict and the government authorities put serious effort into implementing these regulations. Thus this feature leaves room for embodying regulation variables in the pollution demand function.

Assuming concavity of $f(.)$, the inverse pollution demand function can be derived from problem (2)[8]

$$p_e = -\lambda + f_E \tag{3}$$

where λ is the Lagrangian multiplier of environmental requirement for which the regulation strictness may be set as a proxy; f_E is the partial derivative of the production function with respect to pollution emission. It is noteworthy to point out that the above expression is actually a system of equations because there are many pollutants. However, it is difficult to determine whether it is appropriate to estimate the system simultaneously at the aggregate level. An individual firm may discharge only a part of the pollutants, therefore it is hard to say that pollution emissions are jointly or separately decided by the representative firm at the regional aggregation.

There are considerable concerns about the assumption of profit maximization underlying this model. Chinese firms, especially state-owned enterprises (SOEs), have various objectives set by the government, which often contradict the goal of profit maximization. For example, local governments desire to provide social welfare, maintain high employment, and keep economic parity between firms (Ma, 1997). However, the profit

[7] From minimizing abatement cost and pollution levy, Wang and Wheeler (1996) derive the pollution intensity as a function of wastewater amount, output level, influent concentration, concentration standard, and effective levy rate. But they discard the influent concentration and standard variables when specifying the pollution demand function. Therefore their specified demand function is rather *ad hoc* compared to the previously assumed firm's cost minimization behavior.

[8] Throughout this paper, it is assumed, unless specified, that the usual properties of production and utility functions hold and interior solutions exist.

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maximization assumption can be justified on two grounds. First, the share of SOEs in total output has declined over time—firms with other ownerships (collectively owned and private firms), which are assumed to be more market oriented, play a more and more important role in the whole economy. Secondly, economic reforms have been encouraging SOEs to maximize profits.

Environmental supply (the willingness of households to give up environment)
A representative household in the region is assumed to earn a certain amount of income *INC*, which can be spent on a consumption good *X* (the price of consumption good is normalized to be one) to meet its various living demands, and owns a certain environmental endowment *ED*. Part of the income is from earnings in the industrial activities, which is determined by the output price and factor prices *P*.[9] The household could enjoy the environment, and could also supply it to the firm at the ongoing effective rate and use the proceeds to increase consumption of good *X*. Therefore the household's problem is to maximize its utility

$$\begin{aligned} Max_{E} \quad & U(X, ED - E) \\ s.t. \quad & X \leqslant INC(P) + p_e E \end{aligned} \tag{4}$$

One may argue that the environmental quality constraint $ED - E \geqslant 0$ should be imposed to construct the problem. However, it is hard to determine these environment quality constraints. It seems that these constraints, if any, are usually not bounded because there is no evidence that the environmental degradation is so serious that a whole region such as a province is no longer a suitable place for people to live. However this is not a problem because the introduction of the environment into the utility function makes these constraints redundant.

The inverse environmental supply function can be derived by solving the above utility maximization problem

$$p_e = U_2/U_1 \tag{5}$$

where U_1, U_2 are respectively partial derivatives of the utility function with respect to the first (consumption of *X*) and second (consumption of environment) arguments.

The environmental supply function (5) is also a system of equations, but, unlike the demand functions, this supply system definitely needs to be estimated simultaneously because all environmental elements are virtually owned by the representative household.

System (3) and (5) jointly determine the amount of *equilibrium pollution (or environmental use)*. Obviously this approach is similar to the determination of labor supply and the real wage. One may argue that the

[9] When specifying and estimating the model, we treat the per capita income as an exogenous variable for two reasons. One is that in this partial equilibrium setting, income is only weakly linked to the price as some income is earned out of the system. The other one is technical. Endogenizing income provides no better estimation of the system, as many coefficients turn to insignificant.

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environment is a public good and there is open access to it. The firm is a leader in the process who sets the pollution level according to its own problem and the household is a follower who has no control over the pollution emission and therefore the problem (5) is mis-specified. However a number of arguments can be made against this interpretation. First, since the state has assumed rights to the environment within its boundaries and controls access to water and air, for example, we should refer to state property rights. Therefore the open access regime to which no property rights have been assigned is no longer valid in the legal sense (Bromley, 1991). Second, the state property rights enable the representative household, which is a combination of the usual household and the government, to actively participate in the game: it can raise the effective levy rate, through either more strict regulation or more effective regulation enforcement, if it feels that environment is more valuable. Of course, the institutional concerns are still related: whether or not the public interests are well represented and realized by the government, especially for a country like China.

This kind of equilibrium pollution approach is still very much a partial equilibrium analysis. It assumes profit maximization of firms, utility maximization of households (or of the government on behalf of households), and market clearing of the demand and supply of the environmental good. But it is far too simple to have general equilibrium for all factors and products. Although it is not necessarily true in the general equilibrium case, the equilibrium pollution in this setting is a Walrasian equilibrium because it satisfies both profit and utility maximization in a market setting. It turns out that we can use this as a way to test the efficiency of pollution control policies. If we can recover well-behaved demand and supply functions from the observed pollution and prices, then from the theory we can determine whether the underlying policies are desirable. If we can only uncover the demand function because, for example, the supply function is determined by the government not acting in the interest of consumers, then we can at least measure the effectiveness of the pollution abatement policy, but we cannot say anything about the optimality of this policy.

3 Specification of functions

The specification of environmental demand function

Assume Cobb–Douglas technology, that is, for the lth sector, the production function is

$$Y_l = A_l K_l^{\alpha 1 l} L^{\alpha 2 l}{}_l E_l^{\alpha 3 l} \tag{6}$$

then (3) becomes

$$\begin{aligned} p_e + \lambda &= \alpha_{3l} A_l K_l^{\alpha 1 l} L_l^{\alpha 2 l} E_l^{\alpha 3 l - 1} \\ &= \alpha_{3l} Y_l / E_l \end{aligned}$$

As argued above, λ is affected by the regulation. Thus the above expression can be rearranged as

$$E_l / Y_l = \alpha_{3l} / (p_e + g(R))$$

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where R is an index for regulations other than pollution levy. Therefore the pollution intensity can be written as

$$\frac{E}{Y} = \frac{\sum_l E_l}{Y} = \sum_l \frac{\alpha_{3l}}{p_e + g(R)} \frac{Y_l}{Y} = \sum_l \frac{s_l \alpha_{3l}}{p_e + g(R)}$$

that is, the pollution intensity is affected not only by the pollution levy and regulation, but also by sectoral output shares. This makes sense for a number of reasons. First, different sectors employ different levels of technology, that is, have different production functions. Second, the discharge standards and thus pollution levy rates are different across sectors in China. In this study, we divide the industry into two sectors: heavy and light industries. Due to data limitation we cannot estimate different production functions for each region and therefore use as one explanatory factor the share of heavy industry in total industrial output. Similarly, the size and ownership of firms may also affect their behavior and thus are included in the explanatory variables. However, these three variables are highly correlated (0.73 between *HEAVY* and *LARGE*, 0.80 between *HEAVY* and *STATE*, 0.76 between *LARGE* and *STATE*). Including all of these variables in one equation may cause collinearity problems. Therefore we include only one of these in each estimation.

In summary, the environmental demand function for the jth pollutant in the ith region can be specified as[10]

$$\log e_{ji} = \beta_{0j} + \beta_{1j} \log SHARE_i + \beta_{2j} \log p_{eji} + \beta_{3j} \log R_i + \varepsilon_{ji} \qquad (7)$$

where e_i is a set of pollution intensities measured in pollutant discharges (above-concentration standard or excess wastewater, COD, waste gas, and solid wastes) per unit of industrial output; $SHARE_i$ is the share of heavy industry in total industrial output ($HEAVY_i$), or the industrial output share of large enterprises ($LARGE_i$), or the industrial output share of state-owned enterprises ($STATE_i$); p_{ei} is the effective pollution levy rate per unit of pollutant discharge; R_i is a set of regulation indices measured in the implementation ratio of specific environmental regulation, including environmental impact assessment (*EIA*), three synchronization policy (*THREE*), and limited time treatment (*DDLINE*);[11] ε_i is error term.

In the above specification, a positive sign of β_{1j} will be expected when variable $HEAVY_i$ is used because heavy industrial firms are usually heavy polluters, or when variable $STATE_i$ is used and if the soft budget hypothesis of state-owned enterprises holds. When the variable $LARGE_i$ is used, a negative sign of β_{1j} will be expected if scale economies exist in pollution abatement. Negative signs of β_{2j} and β_{3j}'s are expected if the pollution levy system and other regulations play their roles.

[10] This specification is similar to that in Wang and Wheeler (1996). However, we provide profound theoretical ground for this specification.

[11] Please see Appendix for a brief introduction to other pollution control instruments in China.

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The specification of environmental supply function

The inverse environmental supply system (5) implies that the environmental supply is determined by income, environmental endowment and the effective pollution levy rate. That is, the reduced form is

$$E_j = S_j(INC, ED, p_e) \tag{8}$$

where j denotes the pollutants, that is, wastewater (or COD), waste gas (or representative air pollutant), and solid waste.

Note that ED and p_e are vectors, that is, the supply of one environmental good is affected not only by its own endowment and price but also by other elements' endowments and prices as well. However, it is hard to measure endowments for various elements. One appropriate way is to choose land area as a proxy for environmental endowment because nearly all of the environmental elements can be argued to be related to land. And also note that equation (8) is derived from the representative household's utility maximization problem, so E_j, INC and ED are in absolute values. In order to avoid the measurement problem and to coincide with the variable in the demand function, it is natural to scale it down by population, that is, in per capita terms

$$E_j = \frac{emission_j}{population} = \frac{emission_j}{output} \times \frac{output}{population} = e_j \times IND$$

The estimating supply equation for the jth environmental element in the ith region is therefore specified as follows

$$\log e_{ji} + \log IND_i = w_0 + w_{1j} \log INC_i + w_{2j} \log LAND_i + \sum_k w_{3kj} \log p_{eki} + \mu_{ji} \tag{9}$$

where e_{ji} and p_{eki} are defined as the same as above; INC_i is per capita income; $LAND_i$ is per capita land area (reciprocal of population density); IND_i is per capita industrial output; μ_{ji} is error term.

Unlike the approach in Wang and Wheeler (1996), this specification does not include education. Of course education affects people's willingness to supply the environmental good, but education itself is not an independent variable because it is actually affected by the income level. The per capita industrial output is included for a different reason. This appears because of the transformation used rather than for behavioral reasons. One problem with equation (9) is that the dependent variable is actually per capita emission, which is not compatible with the definition of emissions used in the demand function. By putting the term logIND_i in the right-hand side of the equation, we may face a problem of multicollinearity between log IND and log INC_i (actually the correlation is 0.903). Therefore it is appropriate to drop the per capita industrial output when estimating the supply equation.

According to the utility theory, as income rises the demand for leisure and recreation, etc. will rise, that is, the supply of environmental goods will decrease. We therefore expect a negative sign of w_{1j}. In contrast, a larger endowment will lead to a larger environmental supply, that is, the sign w_{2j} would be positive. As the price of a good rises, the supply for that good will increase, therefore a positive sign of w_{3kj} will be expected.

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Table 1. *Variable Definition*

Variable	*Definition*
IWW	Excess wastewater intensity, measured as the amount of wastewater discharge which violates the standard per unit of industrial output (ton/10,000 yuan)
LIWW	Log of IWW
PWW	Effective levy rates for excess wastewater, calculated from dividing total levy collected from excess wastewater discharge by the amount of the amount of excess wastewater discharge (yuan/ton)
LPWW	Log of PWW
IXGAS	Excess waste gas intensity, measured as the volume of waste gas emission which is not treated per unit of industrial output (m^3/yuan)
LIXGAS	Log of IXGAS
PXGAS	Effective levy rate for excess waste gas, calculated from dividing total levy collected from excess waste gas emission by the volume of excess waste gas emission (yuan/10,000m^3)
LPXGAS	Log of PXGAS
ISOLID	Solid wastes intensity, measured as the discharge amount of solid wastes per unit of industrial output (kg/10,000 yuan)
LISOLID	Log of ISOLID
PSOLID	Effective levy rate for solid wastes, calculated from dividing total levy collected from solid wastes discharge by the discharge amount of solid wastes (yuan/ton)
LPSOLID	Log of PSOLID
ICOD	Chemical oxygen demand (COD) intensity, measured as the amount of COD in wastewater per unit of industrial output (kg/10,000 yuan)
LICOD	Log of ICOD
PCOD	Effective levy rate for COD, calculated from dividing total levy collected from excess wastewater discharge by the amount of COD in wastewater (yuan/kg)
LPCOD	Log of PCOD
ISO2	Sulfur dioxide (SO_2) intensity, measured as the amount of SO_2 in waste gas per unit of industrial output (kg/10,000 yuan)
LISO2	Log of ISO2
PSO2	Effective levy rate for SO_2, calculated from dividing total levy collected from excess waste gas discharge by the amount of SO_2 in waste gas (yuan/kg)
LPSO2	Log of PSO2
ISMK	Industrial smoke dust intensity, measured as the volume of smoke dust per unit of industrial output (kg/10,000 yuan)
LISMK	Log of ISMK

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PSMK	Effective levy rate for industrial smoke dust, calculated from dividing total levy collected from excess waste gas by the amount of industrial smoke dust (yuan/kg)
LPSMK	Log of PSMK
IPWD	Industrial powder dust intensity, measured as the amount of powder dust per unit of industrial output (kg/10,000 yuan)
LIPWD	Log of IPWD
PPWD	Effective levy rate for industrial powder dust, calculated from dividing total levy collected from excess waste gas by the amount of powder dust (yuan/kg)
LPPWD	Log of PPWD
IDUST	Industrial dust intensity, measured as the total volume of industrial smoke and powder dusts per unit of industrial output (kg/10,000 yuan)
LIDUST	Log of IDUST
PDUST	Effective levy rate for industrial dust, calculated from dividing total levy collected from excess waste gas discharge by the amount of smoke and powder dusts in waste gas (yuan/kg)
LPDUST	Log of PDUST
HEAVY	Share of heavy industry in total industrial output (%)
LHEAVY	Log of HEAVY
STATE	Share of state-owned enterprises in total industrial output (%)
LSTATE	Log of STATE
LARGE	Share of large enterprises in total industrial output (%)
LLARGE	Log of LARGE
EIA	Enforcement rate of environmental impact assessment (EIA) system, measured as the ratio of the number of projects that pass the EIA procedure in one year to the number of projects which need EIA in that year (%)
LEIA	Log of EIA
THREE	Enforcement rate of 'three-synchronization' system, measured as the ratio of the number of projects that pass the evaluation of this system to the total number of projects in that year (%)
LTHREE	Log of THREE
DDLINE	Enforcement rate of pollution control within deadline, measured as the ratio of the number of pollution control projects that are actually finished in the year to the number of projects that should be finished in that year (%)
LDDLINE	Log of DDLINE
INCOME	Per capita income (yuan)
LINCOME	Log of INCOME
LAND	Per capita land area (m^2)
LLAND	Log of LAND
IND	Per capita industrial output (yuan)
LIND	Log of IND

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4 The data

Data source

As far as we know, a comprehensive data set for undertaking the regression analysis in this study is not available. What we have is environmental and economic data for 28 provinces, autonomous regions, and municipalities directly under the central government in mainland China (Tibet and Hainan are excluded due to missing data) for a five-year period (1992–6), mainly taken from various *China Environmental Yearbooks* and *China Statistical Yearbooks*.

However, the pollution emission data in the *China Environmental Yearbooks* include only those emissions from 'polluting firms owned by governments at and/or above county level'. In order to get the complete picture of emissions, we estimate the total emission using two assumptions: (1) other firms owned by governments at and/or above county level are pollution free; and (2) firms owned by township and village governments and private firms have the same pollution emission ratio as those owned by governments. Therefore, the total emission of one pollutant is calculated as follows

$$e_t = \frac{e_c}{Y_c} \times Y_t$$

where e_t, Y_t are respectively total emission amount and total industrial output value; e_c, Y_c are respectively the emission and output value of firms owned by governments at and/or above county level.

There are no data available for the waste gas and solid waste emissions violating the emissions standard. However, the treated amount of waste gas emissions is identified in the statistics. We assume that those treated discharges meet the emission standard, that is, the excess waste gas emissions are calculated as the difference between total emissions and the treated volume.

The environmental regulation indices are calculated as the enforcement rates of the environmental impact assessment, 'three synchronization', pollution permits and limited time treatment, and the number of staff in environmental protection authorities. The enforcement rate of the pollution permit system is measured as the ratio of the number of firms reporting their emissions to the total number of firms in each region. The enforcement rate of pollution control within the deadline is measured as the ratio of the number of pollution control projects that are actually finished in the year relative to the number of projects that should be finished in that year. The staff is measured in number per 10,000 RMB yuan of industrial output and normalized across regions and over time.

Because the producer price index is not available for every province, the price index of firms' capital investment is used to deflate the output value. The consumer price index is used to calculate real per capita income.

A first look of the data

The data show that there are tremendous variations in effective levy rates across regions. The effective levy rate in 1996, for example, varies from 0.2210 (Shanghai) to 0.0238 Yuan/ton (Hubei) for excess wastewater; from

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Table 2. *Selected statistics for effective levy rates*

Pollutants	*Year*	*Max*	*Min*	*Mean*	*Median*	*Variance*	*Coeff. Variation*
Excess wastewater levy	1992	0.155	0.028	0.071	0.064	0.001	45.485
	1993	0.165	0.024	0.058	0.050	0.001	50.607
	1994	0.140	0.022	0.057	0.047	0.001	51.115
	1995	0.222	0.014	0.066	0.051	0.002	71.213
	1996	0.221	0.024	0.071	0.043	0.003	76.168
COD	1992	0.292	0.035	0.117	0.113	0.003	47.014
	1993	0.249	0.041	0.106	0.080	0.003	54.037
	1994	0.219	0.013	0.098	0.090	0.003	54.799
	1995	0.309	0.025	0.100	0.073	0.006	77.503
	1996	0.292	0.026	0.105	0.070	0.006	75.479
Excess waste gas	1992	3.671	0.341	1.845	1.883	0.500	38.323
	1993	3.573	0.655	1.591	1.641	0.383	38.862
	1994	3.527	0.722	1.625	1.425	0.506	43.781
	1995	5.732	0.434	1.657	1.448	1.297	68.724
	1996	6.458	0.536	1.812	1.463	1.718	72.346
waste gas	1992	0.834	0.057	0.377	0.363	0.024	40.626
	1993	0.547	0.118	0.304	0.275	0.012	36.334
	1994	0.488	0.102	0.278	0.233	0.012	40.216
	1995	0.660	0.087	0.267	0.229	0.022	55.564
	1996	0.637	0.066	0.258	0.198	0.022	57.709
SO_2	1992	0.143	0.004	0.035	0.029	0.001	88.439
	1993	0.081	0.008	0.027	0.023	0.000	67.406
	1994	0.070	0.005	0.024	0.019	0.000	64.481
	1995	0.063	0.005	0.023	0.018	0.000	70.964
	1996	0.063	0.005	0.024	0.018	0.000	70.600
smoke dust	1992	0.085	0.008	0.043	0.040	0.000	49.834
	1993	0.090	0.010	0.037	0.034	0.000	54.278
	1994	0.093	0.008	0.036	0.033	0.000	52.845
	1995	0.157	0.008	0.039	0.030	0.001	82.229
	1996	0.152	0.009	0.041	0.032	0.001	75.469
Powder dust	1992	0.172	0.016	0.061	0.049	0.001	54.360
	1993	0.178	0.019	0.053	0.037	0.001	65.385
	1994	0.165	0.014	0.051	0.040	0.001	62.235
	1995	0.241	0.013	0.053	0.038	0.002	90.537
	1996	0.193	0.015	0.056	0.039	0.002	71.677
Solid wastes	1992	12.774	0.000	1.824	0.987	8.015	155.210
	1993	7.075	0.001	1.335	0.692	2.487	118.105
	1994	5.826	0.000	1.409	0.900	1.804	95.321
	1995	15.755	0.010	2.944	1.304	17.223	140.954
	1996	9.295	0.020	1.683	0.885	4.343	123.829

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0.2924 (Beijing) to 0.0256 yuan/kg (Shandong) for COD; from 6.458438 (Tianjin) to 0.5358 yuan/10,000m^3 (Ningxia) for excess waste gas; from 0.6369 (Xingjiang) to 0.0662 yuan/10,000m^3 (Shandong) for waste gas; from 0.0626 (Heilongjiang) to 0.0052 yuan/kg (Shaanxi) for SO_2; from 0.1522 (Guangdong) to 0.0087 yuan/kg (Shaanxi) for smoke dust; from 0.1934 (Tianjin) to 0.0149 yuan/kg (Shaaxi) for powder dust; and from 9.2953 (Shandong) to 0.0204 yuan/ton (Qinghai) for solid wastes. Moreover, the difference in the effective levy rate across regions tends to increase over time (table 2).

This fact supports the critique that the strictness of enforcement varies widely across regions. However, this disparity in effective rate may be caused by the difference in conditions across regions, which may be desirable in order to achieve cost efficiency. Without further study, we cannot make a judgement based only on this observation.

The second observation from the data is that the effective levy rate in real terms has remained at a similar level or even declined over time (table 2). For example, the average values of effective rates for excess wastewater were respectively 0.0709 in 1992 and 0.0714 in 1996, while the rate for COD decline from 0.1174 to 0.1054 over the same period. A similar phenomenon happens for other pollutants. Given this trend, the relationship between the effective rate and the pollution intensity is really complicated. The difference across regions suggests a negative relation, while the change over time gives another answer (as the intensity declines over time).

In contrast to the levy system, other regulation indices vary across regions by a much smaller degree, and the variation seems to decrease over time (table 3). Except for the permit system, other systems have a much smaller coefficient of variation. This is because these systems have been in place for quite a long time. In contrast, the pollution reporting and

Table 3. *Selected statistics for regulation indices*

Regulations	*Year*	*Max*	*Min*	*Mean*	*Median*	*Variance*	*Coef. Variation*
EIA	1992	100.00	1.46	64.93	70.69	641.53	39.01
	1993	100.00	1.66	66.67	70.94	581.42	36.17
	1994	100.00	14.25	71.36	79.71	546.80	32.77
	1995	100.00	23.35	81.25	87.01	314.22	21.82
	1996	100.00	43.90	84.47	92.45	232.69	18.06
Three synchronizations	1992	100.00	43.36	86.73	89.97	144.13	13.84
	1993	98.53	53.54	84.37	88.55	131.04	13.57
	1994	99.27	69.72	86.64	86.59	57.50	8.75
	1995	96.99	31.62	85.10	88.21	151.10	14.44
	1996	99.80	77.65	98.60	90.00	36.03	6.70
Deadline	1992	143.36	66.28	88.74	89.11	241.58	17.51
	1993	107.26	66.67	85.89	85.00	66.45	9.49
	1994	106.27	26.32	83.02	84.04	198.34	16.96
	1995	125.68	8.06	79.53	82.88	393.23	24.94
	1996	112.00	26.32	78.27	82.28	381.86	24.96

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Table 4. *Selected statistics for pollution intensities*

Pollutants	*Year*	*Max*	*Min*	*Mean*	*Median*	*Variance*	*Coeff. Variation*
Excess wastewater	1992	123.778	14.748	57.061	51.404	868.271	51.640
	1993	104.845	9.799	48.642	43.995	589.205	49.903
	1994	91.493	9.164	40.943	34.051	473.644	53.156
	1995	89.938	5.926	38.156	30.648	506.166	58.963
	1996	93.493	5.669	35.832	28.377	450.826	59.256
COD	1992	102.291	10.583	35.574	32.715	443.222	59.181
	1993	111.826	4.942	28.866	26.360	394.373	68.797
	1994	188.916	6.363	30.308	20.697	1280.385	118.063
	1995	121.001	4.284	28.964	20.756	570.506	82.466
	1996	94.469	4.056	26.162	23.523	328.905	69.321
Excess waste gas	1992	2.733	0.323	1.053	0.894	0.402	60.172
	1993	2.994	0.242	1.017	0.826	0.495	69.191
	1994	2.789	0.196	0.821	0.674	0.334	70.444
	1995	2.337	0.125	0.819	0.679	0.320	69.124
	1996	2.157	0.101	0.782	0.611	0.238	62.394
Waste gas	1992	10.806	1.927	4.867	4.300	5.021	46.037
	1993	10.137	1.582	4.818	4.241	5.508	48.706
	1994	9.280	1.758	4.365	3.874	4.590	49.076
	1995	8.770	1.683	4.244	3.952	3.785	45.837
	1996	9.676	1.646	4.796	4.371	5.138	47.258
SO_2	1992	439.133	19.233	82.910	51.612	7695.435	105.806
	1993	254.386	19.320	71.407	49.715	3120.368	78.228
	1994	255.456	16.601	66.973	46.484	3091.762	83.024
	1995	212.278	13.900	61.182	43.887	2236.278	77.292
	1996	225.722	14.122	64.403	47.015	2696.252	80.626
Smoke dust	1992	332.043	7.997	57.328	45.719	3822.622	107.849
	1993	130.019	8.018	49.783	44.696	1088.934	66.285
	1994	102.265	6.449	41.161	37.939	773.715	67.578
	1995	93.455	5.134	38.672	34.842	692.803	68.062
	1996	105.766	5.368	38.357	34.501	746.195	71.217
Powder dust	1992	79.762	3.676	33.417	30.712	313.399	52.976
	1993	70.523	3.564	32.657	29.979	300.381	53.071
	1994	64.138	2.823	28.017	26.510	251.375	56.591
	1995	76.838	2.422	27.790	26.182	286.178	60.874
	1996	51.483	2.413	25.750	23.816	192.571	53.892
Solid wastes	1992	1331.739	6.387	247.801	68.193	123691.742	141.928
	1993	954.771	5.496	192.202	60.501	57974.905	125.274
	1994	836.640	1.855	150.283	48.222	41082.631	134.872
	1995	842.621	1.155	152.604	53.641	57013.677	156.467
	1996	764.081	1.379	109.845	50.467	25644.420	145.786

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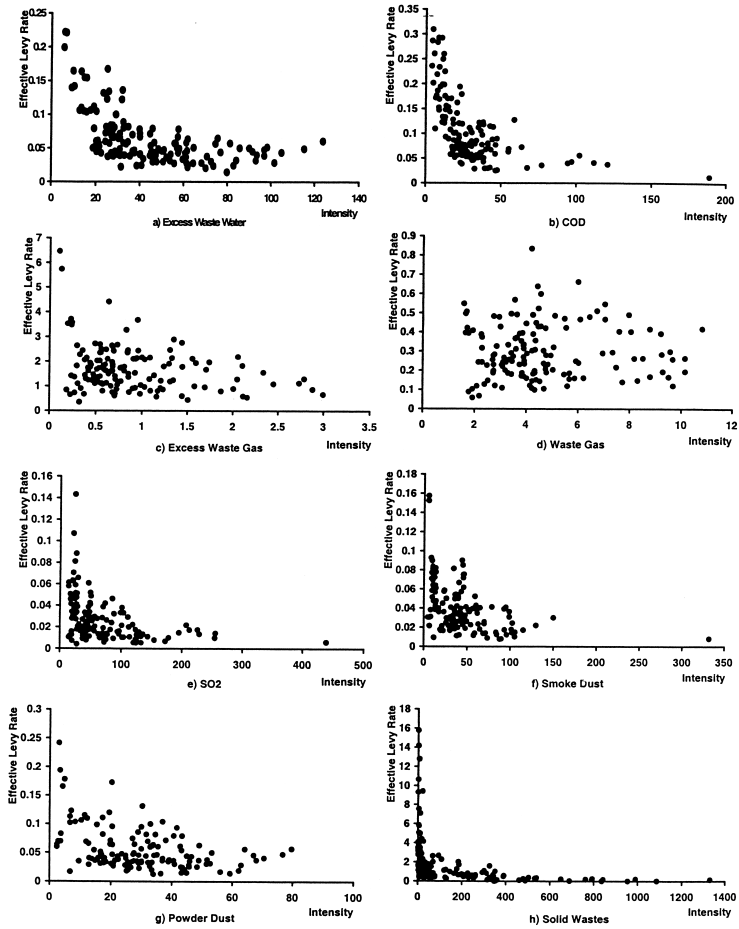


Figure 1. *Effective Levy Rate vs Emission Intensity*

permit system is in the preliminary stage of its implementation and the data about it may be unreliable. Given this we decided to drop the index for the permit system in the following analysis.

The pollution intensities decrease steadily over time. In contrast to popular perception, this fact suggests that China has managed to prevent the environment from deteriorating further while maintaining a path of economic development. This will be discussed further in the following section. The variance in pollution intensities across regions is slightly higher than that in effective levy rates, but, in contrast to the trend of levy rates, the variance in intensities tends to dampen over time (table 4).

Finally, plotting effective levy rates against the intensity for each pollutant clearly shows that there is a negative relation between them (figure

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1). This implies that there may exist a reasonably well-behaved demand function for the environmental good.

5 Econometric results

The estimation has been undertaken in several ways. First, the demand and supply functions are estimated separately to serve as a reference. Secondly, all the demand and supply equations for three types of pollutants (water, air, and solid wastes) are estimated as one system of equations. Thirdly, because the levy collected from solid wastes is only a minor part of the total amount collected, and there are some missing observations in this series, the system is estimated including only equations for water and air pollutants. We also estimate a reduced-form function by putting all independent variables in one equation. During each stage of estimation, both pooled and fixed-effect models are used. In addition, different types of specification are also tested in the process. Some estimation results are reported in tables 5–12.

Water pollution

The demand and supply for excess wastewater looks well behaved when the system is estimated independent to other pollutants. For example, when the inverse supply function is specified (lower part of table 5), the coefficients of LIWW and LPWW have expected signs and are significant at the 5 per cent level. The price elasticity demand is −1.3142, implying the effective wastewater levy rate has a strong influence on the demand for

Table 5. *Joint estimation of demand and supply functions for excess wastewater*

	Demand LPWW			*Supply LIWW*	
	Coefficient	*t-ratio*		*Coefficient*	*t-ratio*
LHEAVY	0.74195	4.756***	LINCOME	−0.98893	−3.63***
LEIA	0.1004	2.799***	LLAND	4.2184	2.906***
LTHREE	0.15982	1.254	LPWW	0.26015	1.029
LDDLINE	3.99E-02	0.5646	LPXGAS	−4.49E-02	−0.7793
LIWW	−0.31975	−2.14**	LPSOLID	−5.95E-03	−0.2702
DW = 1.4189			DW = 2.4280		
	Demand LIWW			*Supply LPWW*	
	Coefficient	*t-ratio*		*Coefficient*	*t-ratio*
LHEAVY	1.36400	4.321***	LINCOME	1.6416	1.688*
LEIA	0.05828	0.7185	LLAND	−11.605	−3.168***
LTHREE	0.28405	1.605	LIWW	2.0496	2.426**
LDDLINE	0.14571	1.499			
LPWW	−1.31420	−2.244**			
DW = 1.1263			DW = 2.3772		

Notes: *** denotes significant at 1 per cent level; ** significant at 5 per cent level; * significant at 10 per cent level.

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Table 6. *Joint estimation of demand and supply functions for excess waste gas*

	Demand LIXGAS			*Supply LPXGAS*	
	Coefficient	*t-ratio*		*Coefficient*	*t-ratio*
LHEAVY	0.56644	5.954***	LINCOME	−0.68025	−1.804*
LEIA	−0.12556	−3.391***	LLAND	5.6023	2.814***
LTHREE	0.42453	3.436***	LPWW	0.46103	4.16***
LDDLINE	0.26535	4.08***	LIXGAS	−1.0344	−3.196***
LPXGAS	2.37E-02	0.2429	LPSOLID	5.43E-02	1.805*
DW = 2.0193			DW = 2.3772		

	Demand LPXGAS			*Supply LIXGAS*	
	Coefficient	*t-ratio*		*Coefficient*	*t-ratio*
LHEAVY	0.23177	0.6446	LINCOME	−0.67291	−4.233***
LEIA	0.22223	2.305**	LLAND	3.8943	4.201***
LTHREE	−0.50314	−1.514	LPWW	0.14592	1.885*
LDDLINE	−6.07E-02	−0.315	LPXGAS	−0.35195	−3.487***
LIXGAS	0.15138	0.2796	LPSOLID	2.26E-03	0.1304
DW = 2.1966			DW = 1.8005		

Notes: *** denotes significant at 1 per cent level; ** significant at 5 per cent level; * significant at 10 per cent level.

Table 7. *Joint estimation of demand and supply functions for solid wastes*

	Demand LISOLID			*Supply LPSOLID*	
	Coefficient	*t-ratio*		*Coefficient*	*t-ratio*
LHEAVY	1.4848	6.499***	LINCOME	1.717	0.7618
LEIA	−0.12638	−1.384	LLAND	1.062	0.1818
LTHREE	0.29825	0.9941	LPWW	0.97776	2.647***
LDDLINE	0.19108	1.17	LPXGAS	0.37593	2.075**
LPSOLID	−0.27548	−2.064*	LISOLID	−0.0325	−0.0383
DW = 1.4753			DW = 1.6415		

	Demand LPSOLID			*Supply LISOLID*	
	Coefficient	*t-ratio*		*Coefficient*	*t-ratio*
LHEAVY	0.51779	0.8636	LINCOME	−2.2846	−2.739***
LEIA	0.20707	1.4	LLAND	3.6157	1.352
LTHREE	−0.43071	−0.8481	LPWW	−0.14807	−0.3466
LDDLINE	−3.45E-02	−0.1231	LPXGAS	0.0944	0.4413
LISOLID	−0.49322	−1.611	LPSOLID	−0.21122	−0.4966
DW = 1.5508			DW = 1.6274		

Notes: *** denotes significant at 1 per cent level; ** significant at 5 per cent level; * significant at 10 per cent level.

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Table 8. *Joint estimation of demand and supply functions for excess wastewater, excess waste gas and solid wastes (including LHEAVY)*

	Demand function				*Supply function*		
	LIWW	*LIXGAS*	*LISOLID*		*LPWW*	*LPXGAS*	*LPSOLID*
LHEAVY	1.27630 4.088***	0.30304 1.586	1.3303 3.295***	LINCOME	−3.4404 −1.306	−2.0317 −1.882*	2.3543 0.9561
LEIA	0.01355 0.165	−0.28788 −3.262***	0.16798 0.5488	LLAND	5.6745 0.6408	3.2744 0.657	−7.48764 −0.6651
LTHREE	0.25298 1.356	0.78963 3.155***	0.16301 0.2312	LIWW	−0.68897 −0.3551		
LDDLINE	0.10733 1.035	0.27221 2.35***	0.13644 0.5355	LIXGAS		−0.31624 −0.4167	
LPWW	−1.01010 −1.760*			LISOLID			0.57368 0.4373
LPXGAS		0.79057 2.414***		LPWW		−0.78038 −1.661*	0.23382 0.2519
LPSOLID			−0.96522 −1.249	LPXGAS	−1.6477 −2.05**		0.83878 2.295**
				LPSOLID	1.9213 2.281**	1.1658 2.759**	
DW	1.0468	2.3328	1.3683		1.6601	1.6374	1.7329

Notes: The first figure in each cell is the estimated coefficient and the second one is the t-ratio; *** denotes significant at 1 per cent level; ** significant at 5 per cent level; * significant at 10 per cent level.

Table 9. *Joint estimation of demand and supply functions for excess wastewater and excess waste gas*

	Demand function			*Supply function*	
	LPWW	*LPXGAS*		*LIWW*	*LIXGAS*
LHEAVY	0.66972	−0.1457	LINCOME	−0.96635	−0.50592
	4.289***	−0.3493		−3.381***	−1.807*
LEIA	0.10423	0.31722	LLAND	4.3528	5.0151
	2.735***	2.87***		2.902***	3.425***
LTHREE	0.20225	−0.72873	LPWW	0.26231	0.52821
	1.619	−1.876*		0.9324	1.99**
LDDLINE	8.29E-02	−0.1855	LPXGAS	4.17E-02	−0.40456
	1.304	−0.8777		0.3089	−3.187***
LIWW	−0.25299		LPSOLID	6.03E-03	1.35E-02
	−1.659*			0.2194	0.5043
LIXGAS		0.80652			
		1.272			
DW	1.4781	2.3164		2.4419	1.8732

Notes: The first figure in each cell is the estimated coefficient and the second one is the t-ratio; *** denotes significant at 1 per cent level; ** significant at 5 per cent level; * significant at 10 per cent level.

wastewater. When the inverse demand function is specified and other effective levy rates are added into supply function (upper part of table 5), the relevant coefficients also have the expected sign, but the coefficient of LPWW in the supply function becomes insignificant. The situation becomes worse when the system is estimated jointly with the demand and supply of excess waste gas and solid wastes (tables 8–9). We hardly find a well-behaved demand and supply function of excess wastewater in these specifications. This suggests that the levy system may be efficient in the single market for wastewater, but it is not efficient in the whole environmental market or it may suggest a specification problem in the waste gas part of the model. This might be in turn partly determined by the nature of water pollution which tends to be more local than air pollution. Local residents are more aware of the water quality problem and more likely to push local government to set more efficient policy to control water pollution.

Even if we acknowledge that the wastewater market is efficient, there is still room for policy improvement. Referring to figure 1, the equilibrium intensities and prices are quite diverse across regions. These outcomes are optimal only when each region is isolated from each other, and there must exist some barrier restricting the integration of the pollution market. This 'autarky' state leads to unequal levy rates, therefore an 'opening up' policy may help to get a Pareto improvement. For example, industrial relocation

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Table 10. *Joint estimation of demand and supply functions for excess wastewater, excess waste gas and solid wastes (including LSTATE)*

	Demand			*Supply*	
	Coefficient	*t-ratio*		*Coefficient*	*t-ratio*
Dependent variable: LIWW			Dependent variable: LPWW		
LSTATE	0.92342	9.595***	LINCOME	−0.61297	−0.4936
LEIA	−4.89E-02	−1.357	LLAND	−5.3543	−1.396
LTHREE	0.20356	2.268**	LIWW	0.36561	0.5005
LDDLINE	0.11253	2.216**	LPXGAS	7.84E-02	0.176
LPWW	−0.24564	−1.081	LPSOLID	9.87E-02	0.2152
	DW = 1.8188			DW =1.9016	
Dependent variable: LIXGAS			Dependent variable: LPXGAS		
LSTATE	0.55056	5.191***	LINCOME	−2.6883	−1.495
LEIA	−0.13957	−2.588***	LLAND	−2.9472	−0.2828
LTHREE	0.54469	3.185***	LPWW	−1.8571	−1.003
LDDLINE	0.22992	2.682***	LIXGAS	−0.23724	−0.2441
LPXGAS	0.15209	0.892	LPSOLID	1.1599	2.278**
	DW = 2.1330			DW = 1.6781	
Dependent variable: LISOLID			Dependent variable: LPSOLID		
LSTATE	1.2823	2.926***	LINCOME	2.7848	0.8485
LEIA	0.24162	0.6465	LLAND	6.2042	0.2742
LTHREE	1.60E-02	1.93E-02	LPWW	2.3535	0.9187
LDDLINE	0.18177	0.5507	LPXGAS	0.59571	1.392
LPSOLID	−1.0424	−1.067	LISOLID	−2.65E-02	−1.23E-02
	DW = 1.5067			DW = 1.6883	

Notes: *** denotes significant at 1 per cent level; ** significant at 5 per cent level; * significant at 10 per cent level.

may reduce the enforcement cost in the regions with higher pollution levy rates, and increase the revenue in the regions with lower rates. Unfortunately, the current environmental policy may enhance the barrier to open up, in addition to other natural and economic considerations. One guideline of environmental protection in China is 'prohibiting firms from shifting polluting workshops or production processes into other regions'. According to the results we present here, this guideline needs to be reviewed.

When the excess wastewater is replaced by chemical oxygen demand (COD) as the representative water pollutant, the estimated coefficients are not significant in most cases. This might be the result of a measurement problem. The levy is collected from the excess wastewater, which violate the discharge standards, but COD is calculated from all wastewater discharges.

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Table 11. *Joint estimation of demand and supply functions for excess wastewater, excess waste gas and solid wastes (including LLARGE)*

	Demand			*Supply*	
	Coefficient	*t-ratio*		*Coefficient*	*t-ratio*
Dependent variable: LIWW			Dependent variable: LPWW		
LLARGE	−0.49009	−1.249	LINCOME	−3.1946	−0.2187
LEIA	−0.22105	−3.025***	LLAND	40.743	1.3
LTHREE	−6.72E-02	−0.2746	LIWW	−3.1407	−0.4467
LDDLINE	0.22202	1.627	LPXGAS	3.6384	0.1633
LPWW	1.0845	2.285**	LPSOLID	−0.49874	−2.54E-02
	DW = 1.9192			DW = 1.9756	
Dependent variable: LIXGAS			Dependent variable: LPXGAS		
LLARGE	−0.38119	−0.9183	LINCOME	−1.4877	−1.652*
LEIA	−0.25069	−2.372**	LLAND	6.1438	1.649*
LTHREE	0.60398	1.749*	LPWW	−0.30063	−0.9031
LDDLINE	0.28012	1.708*	LIXGAS	−1.67E-02	−0.1426
LPXGAS	0.62404	1.493	LPSOLID	1.2412	3.501***
	DW = 2.2001			DW = 1.6409	
Dependent variable: LISOLID			Dependent variable: LPSOLID		
LLARGE	1.0688	0.6437	LINCOME	1.401	1.577
LEIA	1.2923	1.782*	LLAND	−5.5738	−1.431
LTHREE	−1.4323	−1.039	LPWW	0.32856	0.877
LDDLINE	−0.29686	−0.6663	LPXGAS	0.74333	1.9*
LPSOLID	−4.2586	−2.043**	LISOLID	6.88E-02	0.969
	DW = 1.6567			DW = 1.6427	

Notes: *** denotes significant at 1 per cent level; ** significant at 5 per cent level; * significant at 10 per cent level.

Air pollution

The demand for and supply of excess waste gas and other air pollutants are not well behaved according to the estimation (tables 6, 8–9). In some cases, the coefficients are significant, but have the 'wrong' sign. This is partly due to the measurement problem as they are calculated from the total emission no matter whether they violate the emission standards or not, but the levy is collected for excess emissions. However, the main reason is that the market for air pollutant may not be efficient. More specifically, this is because the price on the supply side is set arbitrarily by the environmental authority, and most likely does not take into account utility maximization. This argument can be justified by looking at figure 1, where the plotting shows a well-defined demand curve. We also estimate the reduced-form function of this system separately for each pollutant, and find that the coefficients of own price are significant and have the sign consistent with a demand function, and the equations fit the data well

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(table 12). Another piece of evidence is that other coefficients in the system are usually significant and have the 'correct sign', implying that the specification is correct.

Solid wastes

Similar phenomena for solid wastes (table 7) are observed as for air pollutants. Besides data problems, this also suggests that the levy system does not work well for solid wastes.

Other regulations

EIA has significant negative effects on the demand for pollution in some cases. The environmental regulation indices (capturing 'three-synchronization' and limited time treatment approaches) have insignificant effects, and in some cases even significant positive effects. The positive effects suggest that a higher enforcement rate of these environmental regulations leads to higher pollution intensity! There are several explanations for this result. First, as we noted above, these regulation indices are of similar values across regions, therefore it is natural to have an insignificant coefficient in the regression. However, this does not mean they are not effective. Secondly, recall the origin of these indices (equation (3)). These indices serve as a proxy for the Lagrangian multiplier of environmental supply constraints, as these regulations put restrictions on the use of the environmental good. Therefore there is a mutual causality between these indices and environmental demand (in our estimation it is the realized intensity or levy rate). It is true that higher regulation enforcement is expected to help reduce the demand for environmental goods, but the higher indices may well be the reaction to the higher pollution intensity. This may explain why they sometimes have significant positive coefficients. One way around this would be to endogenize these regulation indices in the system. This is left for future work. Finally, of course this may also be due to the weak mechanism of these regulations. For example, as we pointed out above, the three-synchronization system may be in effect in only one specific time: when the firm is waiting for approval of an operation. After the approval, the pollution control facilities may be shut down and therefore have no effect on the pollution control. In this sense, a high index does not necessarily represent high or tight enforcement.

Economic structure

The share of heavy industry has a significant positive effect on the demand for pollution (tables 5–9). This is straightforward because they are heavily polluting firms. The share of state-owned enterprises (SOEs) in industrial output has a significantly positive coefficient as well (table 10). This positive relationship may be due to two factors. As we noted above, SOEs are more likely to be heavy industrial firms which need more pollutants for operation. The other one is the so-called 'soft-budget hypothesis'. As the enterprises are owned by the government, SOEs lack incentives to maximize their profits and are less efficient, thus they produce more pollutants.

The coefficient of the share of large enterprises is insignificant (table 11). This is also quite understandable. Large enterprises are more likely to be

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Table 12. *Estimation of reduced-form functions*

Dependent variable		*Explanatory variables*								
		LHEAVY	*LEIA*	*LTHREE*	*LDDLINE*	*LINCOME*	*LLAND*	*LPWW*	*LPXGAS*	*LPSOLID*
LIWW	coefficient	0.28727	0.069426	0.091614	0.061602	−0.92543	3.7377	−0.21473	−0.03015	0.000301
	t-ratio	2.82	2.263	1.023	1.255	−5.054	3.883	−3.724	−0.8723	0.02134
	R-square		0.71120			adjusted	0.6935			
LIXGAS	coefficient	0.24486	0.035721	0.21914	0.18866	−0.42458	3.9064	0.080282	−0.30908	0.000932
	t-ratio	2.333	1.13	2.374	3.731	−2.251	3.938	1.351	−8.68	0.06416
	R-square		0.67330			adjusted	0.6534			
LISOLID	coefficient	0.477	0.088957	0.22973	0.050507	−1.5966	5.8472	−0.10451	0.14778	−0.25295
	t-ratio	1.457	0.9027	0.7984	0.3204	−2.715	1.891	−0.5643	1.331	−5.583
	R-square		0.51710			adjusted	0.4876			
		LHEAVY	*LEIA*	*LTHREE*	*LDDLINE*	*LINCOME*	*LLAND*	*LPWW*	*LPSO2*	*LPSOLID*
LIWW	coefficient	0.294	0.058807	0.11031	0.059759	−0.92575	3.4429	−0.23641	0.013819	−0.00203
	t-ratio	2.889	1.956	1.254	1.191	−5.043	3.56	−4.082	0.3561	−0.1444
	R-square		0.70980			adjusted	0.692			
LISO2	coefficient	0.120	0.082075	−0.03315	−0.05637	−0.32283	3.5638	0.060368	−0.19961	0.011705
	t-ratio	1.278	2.968	−0.4097	−1.222	−1.912	4.006	1.133	−5.592	0.9049
	R-square		0.42010			adjusted	0.3847			
LISOLID	coefficient	0.448	0.10906	0.16666	0.012959	−1.5797	6.1411	−0.08205	0.11341	−0.24844
	t-ratio	1.369	1.128	0.589	0.08034	−2.676	1.974	−0.4405	0.9086	−5.493
	R-square		0.51370			adjusted	0.484			
		LHEAVY	*LEIA*	*LTHREE*	*LDDLINE*	*LINCOME*	*LLAND*	*LPWW*	*LPSMK*	*LPSOLID*
LIWW	coefficient	0.294	0.06044	0.10908	0.062486	−0.92822	3.4994	−0.2329	0.006187	−0.00179
	t-ratio	2.888	2.034	1.24	1.264	−5.051	3.661	−4.021	0.1607	−0.1269
	R-square		0.70950			adjusted	0.6918			

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LISMK	coefficient	0.174	0.12422	−0.04338	0.047721	−0.55059	4.7872	0.07649	−0.23855	0.006941
	t-ratio	1.629	3.982	−0.4697	0.9195	−2.854	4.772	1.258	−5.904	0.4688
	R-square		0.58750			adjusted	0.5623			
LISOLID	coefficient	0.459	0.11138	0.16949	0.023954	−1.6179	6.1719	−0.09283	0.13599	−0.25042
	t-ratio	1.402	1.168	0.6	0.1509	−2.742	2.012	−0.4993	1.101	−5.531
	R-square		0.51510			adjusted	0.4855			

		LHEAVY	*LEIA*	*LTHREE*	*LDDLINE*	*LINCOME*	*LLAND*	*LPWW*	*LPPWD*	*LPSOLID*
LIWW	coefficient	0.294	0.058702	0.113	0.062495	−0.93195	3.4425	−0.23498	0.010335	−0.00191
	t-ratio	2.889	1.905	1.26	1.269	−5.05	3.466	−4.039	0.2648	−0.1358
	R-square		0.70960			adjusted	0.6919			
LIPWD	coefficient	0.139	0.024339	0.22153	0.085505	−0.78428	1.7438	0.042175	−0.19155	0.010407
	t-ratio	1.510	0.8738	2.733	1.92	−4.702	1.943	0.802	−5.429	0.8182
	R-square		0.61330			adjusted	0.5897			
LISOLID	coefficient	0.447	0.11737	0.17116	0.038363	−1.6124	6.4558	−0.05242	0.047524	−0.24598
	t-ratio	1.362	1.181	0.5919	0.2416	−2.71	2.017	−0.2795	0.3776	−5.422
	R-square		0.51110			adjusted	0.4813			

		LHEAVY	*LEIA*	*LTHREE*	*LDDLINE*	*LINCOME*	*LLAND*	*LPWW*	*LPDUST*	*LPSOLID*
LIWW	coefficient	0.295	0.058675	0.11249	0.061511	−0.93151	3.4343	−0.2371	0.014972	−0.0021
	t-ratio	2.896	1.951	1.27	1.245	−5.064	3.539	−4.07	0.3723	−0.1491
	R-square		0.70980			adjusted	0.6921			
LIDUST	coefficient	0.169	0.080585	0.082717	0.04942	−0.64539	3.2941	0.037428	−0.16857	0.00921
	t-ratio	1.816	2.941	1.025	1.098	−3.851	3.726	0.7052	−4.601	0.7182
	R-square		0.59960			adjusted	0.5751			
LISOLID	coefficient	0.454	0.11091	0.17957	0.029396	−1.6217	6.1804	−0.07961	0.10578	−0.24831
	t-ratio	1.385	1.146	0.6302	0.185	−2.74	1.979	−0.4247	0.8174	−5.482
	R-square		0.51310			adjusted	0.4833			

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		LHEAVY	*LEIA*	*LTHREE*	*LDDLINE*	*LINCOME*	*LLAND*	*LPCOD*	*LPXGAS*	*LPSOLID*
LICOD	coefficient	0.514	0.042018	0.25534	0.048525	−1.0141	1.2089	−0.71161	0.042622	0.063221
	t-ratio	3.640	0.9663	2.043	0.6999	−3.895	0.9132	−12.96	0.8806	3.217
	R-square		0.67170			adjusted	0.6517			
LIXGAS	coefficient	0.251	0.030296	0.23001	0.18672	−0.40133	3.7769	0.069155	−0.31131	0.009795
	t-ratio	2.449	0.9596	2.534	3.709	−2.123	3.929	1.734	−8.858	0.6863
	R-square		0.67620			adjusted	0.6564			
LISOLID	coefficient	0.414	0.087506	0.19654	0.051081	−1.522	6.4347	0.038727	0.1193	−0.2566
	t-ratio	1.287	0.8843	0.6909	0.3238	−2.569	2.136	0.3098	1.083	−5.737
	R-square		0.51630			adjusted	0.4868			

		LHEAVY	*LEIA*	*LTHREE*	*LDDLINE*	*LINCOME*	*LLAND*	*LPCOD*	*LPSO2*	*LPSOLID*
LICOD	coefficient	0.498	0.032789	0.24507	0.016516	−0.99629	0.84551	−0.72203	0.11804	0.058382
	t-ratio	3.586	0.7802	2.025	0.2382	−3.889	0.6496	−13.63	2.261	3.059
	R-square		0.68220			adjusted	0.6628			
LISO2	coefficient	0.095	0.069664	−0.02784	−0.05459	−0.24482	3.6653	0.12638	−0.2118	0.021874
	t-ratio	1.075	2.618	−0.3633	−1.243	−1.509	4.448	3.767	−6.408	1.81
	R-square		0.47170			adjusted	0.4394			
LISOLID	coefficient	0.391	0.10304	0.14763	0.022034	−1.5009	6.6816	0.059066	0.084809	−0.25023
	t-ratio	1.215	1.057	0.526	0.137	−2.526	2.214	0.4807	0.7006	−5.656
	R-square		0.51380			adjusted	0.4841			

		LHEAVY	*LEIA*	*LTHREE*	*LDDLINE*	*LINCOME*	*LLAND*	*LPCOD*	*LPSMK*	*LPSOLID*
LICOD	coefficient	0.508	0.040412	0.24336	0.032912	−1.0306	1.0492	−0.72173	0.10332	0.058602
	t-ratio	3.643	0.9682	2.002	0.4788	−4.003	0.8099	−13.49	1.976	3.039
	R-square		0.67930			adjusted	0.6598			
LISMK	coefficient	0.160	0.11315	−0.03445	0.047213	−0.48665	4.7814	0.11417	−0.24762	0.017719
	t-ratio	1.565	3.687	−0.3854	0.9342	−2.571	5.02	2.903	−6.443	1.25

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	R-square		0.60770			adjusted	0.5838			
LISOLID	coefficient	0.398	0.10479	0.14882	0.029956	−1.5319	6.7053	0.052145	0.10561	−0.253
	t-ratio	1.238	1.089	0.5309	0.189	−2.58	2.244	0.4226	0.876	−5.689
	R-square		0.51480			adjusted	0.4852			
		LHEAVY	*LEIA*	*LTHREE*	*LDDLINE*	*LINCOME*	*LLAND*	*LPCOD*	*LPPWD*	*LPSOLID*
LICOD	coefficient	0.503	0.027133	0.27864	0.038136	−1.0634	0.64459	−0.72535	0.10979	0.058578
	t-ratio	3.609	0.6307	2.264	0.5572	−4.119	0.4826	−13.51	2.072	3.05
	R-square		0.68030			adjusted	0.6607			
LIPWD	coefficient	0.122	0.017202	0.22118	0.085477	−0.72372	1.8585	0.088596	−0.20373	0.017821
	t-ratio	1.376	0.6293	2.828	1.966	−4.411	2.19	2.596	−6.051	1.46
	R-square		0.63040			adjusted	0.6078			
LISOLID	coefficient	0.398	0.1129	0.14816	0.041648	−1.5201	6.9781	0.071465	0.01901	−0.24511
	t-ratio	1.233	1.133	0.5197	0.2628	−2.542	2.256	0.5745	0.1549	−5.51
	R-square		0.51210			adjusted	0.4823			
		LHEAVY	*LEIA*	*LTHREE*	*LDDLINE*	*LINCOME*	*LLAND*	*LPCOD*	*LPDUST*	*LPSOLID*
LICOD	coefficient	0.506	0.032986	0.26171	0.032185	−1.0459	0.809	−0.72617	0.12266	0.0576
	t-ratio	3.642	0.7854	2.154	0.4706	−4.076	0.62	−13.6	2.264	3.006
	R-square		0.68220			adjusted	0.6628			
LIDUST	coefficient	0.14442	0.071	0.082744	0.05032	−0.57544	3.4346	0.099303	−0.18343	0.016866
	t-ratio	1.63100	2.664	1.068	1.153	−3.515	4.126	2.917	−5.308	1.38
	R-square		0.62260			adjusted	0.5995			
LISOLID	coefficient	0.397	0.10546	0.15653	0.034849	−1.5324	6.73	0.059327	0.073918	−0.24971
	t-ratio	1.232	1.082	0.5553	0.2196	−2.574	2.223	0.479	0.588	−5.616
	R-square		0.51330			adjusted	0.4835			

heavy industrial firms and SOEs, and therefore tend to want to undertake more pollution. However, large enterprises are well equipped and have scale economy of pollution controls, and they are also closely monitored because monitoring is easy to do. These two opposing effects may cause its coefficient to be insignificant.

Other factors

The per capita income and the environmental endowment proxy (per capita land area or reciprocal of population density) are crucial for determining the supply of the environmental good. In most cases, as we expect, their coefficients are significant and have the 'correct' sign (even in the case where the pollution levy rate or intensity is not significant). The higher per capita income level, the less willing is the household to supply the environment good; the more environmental endowment, the more there is to supply of it. This is especially clear when the supply equation is estimated as the normal form (tables 5–8). This may enhance the argument that because households do not set the levy rate, which is done arbitrarily by a central policy body, there is no way of measuring the underlying supply function for environment by households.

To compare this study with previous results, we reestimate the system including the education factor in the supply function. Education is measured as the percentage of people who receive high school and higher education in total population. It turns out that the parameter of education variable in all the estimates is insignificant except one where the parameter is positively significant with 10 per cent confidence (table 13). This confirms our argument that the education variable need not to be included in the supply function primarily because it is highly correlated with income.

7 Conclusion

We have set out an equilibrium model of pollution and estimated the model using a detailed cross-sectional/time series data set for China from 1992 to 1996. The study has shown that China's pollution levy system

Table 13. *Testing education effect*

Dependent variable	*Coefficient of education variable*	*p-value*	
LIWW	−0.38323	0.226	Corresponding to the lower part of table 5.
LPWW	−0.17449	0.796	Corresponding to the upper part of table 5.
LPXGAS	0.80019	0.096	Corresponding to the upper part of table 6.
LIXGAS	−0.36144	0.151	Corresponding to the lower part of table 6.
LPSOLID	0.27382	0.821	Corresponding to the upper part of table 7.
LISOLID	−0.33382	0.621	Corresponding to the lower part of table 7.
LPW	−0.25638	0.879	Corresponding to table 8
LPXGAS	0.32057	0.784	
LPSOLID	−0.24791	0.815	
LIWW	−0.52847	0.148	Corresponding to table 9
LIXGAS	−0.26551	0.458	

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appears to be effective in the sense that firms respond well to the effective levy rate in the well-behaved demand functions for pollution. The pollution levy system appears to work better for wastewater than for other pollutants.

However, because the supply functions could not be estimated, we can say very little about the efficiency of environmental regulation in China. This may be because due to data problems, we were unable to identify the supply functions, even though they exist. Or it could be that the government sets environmental controls without reference to the preferences of households. Despite this disappointing aspect of the results, what we can say is that the differential effective levy rates across regions in China, imply that the enforcement cost could be reduced and overall welfare could be raised by withdrawing some restrictions.

There is a great deal more research that could be undertaken using the framework developed here. Better firm-level data would help enormously as the aggregate data masks many important issues in Chinese environmental regulation.

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Appendix: China's pollution control policy instruments other than pollution levy

Environmental impact assessment

Clause 6 of the 1979 provisional environmental protection law states; 'All enterprises and institutions shall pay adequate attention to the prevention of pollution and damage to the environment during site selection, design, construction, and operation. Project design cannot be started until the report on the potential environmental effects has been reviewed and approved by the responsible environmental protection department and other relevant administrative department…'

Formal implementation of EIA was followed by an administrative order from National Environmental Protection Commission in 1981. New projects are required to fill in a simple environmental impact assessment form or carry out a formal EIA procedure according to the nature and size of the proposed project that also determines the jurisdiction of evaluating and approving the EIA report between environmental protection authorities at different level.

Similar to the practice in other countries, an EIA for a proposed project involves assessing the existing environmental quality of the project site, predicting the effect on environmental quality of the project, and raising some recommendations on how to mitigate the adverse effects. However, the public in China has little chance to participate in the EIA process.

The practice of EIA in China is often criticized as 'merely following the procedure and making a gesture to give the impression of doing something' because the proposed projects are usually backed by the government.

Three-synchronization policy

The three-synchronization policy requires that the design, construction, and operation of a new production facility be synchronized with the design, construction, and operation of appropriate waste treatment facilities. A production facility cannot be put into operation without passing the evaluation of this three-synchronization requirement by environmental protection authorities and line industrial administrative authorities.

This policy is also criticized as 'making a gesture' because firms may just shut down the waste treatment facilities after passing the evaluation. Actually this has been a common practice of firms, especially township and village enterprises. Not only is nothing contributed to environmental protection, but also resources to build those treatment facilities, which may never be used, are wasted.

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Limited time treatment
Every year, environmental protection authorities identify some heavily polluting factories in their jurisdictions and set deadlines for these firms to treat their pollution to meet the standard. If the requirement is not met in time, the firm will be ordered to temporarily halt its production, or even be closed or relocated.

Pollution report and discharge permit system requires polluting factories to report their pollution discharge to local environmental authorities and then a discharge permit is issued according to the situation. Although it has been implemented for several years, this system is still at the preliminary stage because it is difficult and costly to determine the appropriate number of permits, and no market for the permit emerged.

Centralized pollution control has been encouraged because it may provide scale economies and is cost efficient.

Environmental responsibility system usually refers to the environmental protection contract signed by government leaders at different levels. This system is mainly designed as a tool to draw more attention on environmental protection from government leaders.

Assessment of urban environmental quality is conducted annually and the result is reported in the media. This puts public pressure on local government to improve environmental quality.

Taxation exemption or deduction is granted to firms using or recycling wastes; however, it is beyond the control of local environmental authorities.

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