Environment and Development Economics 8: 451–466 © 2003 Cambridge University Press
DOI:10.1017/S1355770X0300024X Printed in the United Kingdom

Equilibrium pollution and economic development in China

HUA WANG and DAVID WHEELER
Development Research Group, World Bank, 1818 H St. N.W., Washington, DC 20433 USA. Email: HWANG1@worldbank.org.

ABSTRACT. This paper develops and estimates a structural equilibrium pollution model, in which the price and quantity of industrial pollution are jointly determined by the intersection of environmental demand and supply functions. The industrial environmental demand function relates industrial pollution intensity to the local price of pollution, while controlling for characteristics such as sector, scale, and ownership. The local environmental supply function specifies the pollution price imposed by the host community as pollution rises. The model provides a good fit to available data on provincial variations in China's pollution levy, or industrial emissions charge. Our results also suggest that Chinese industry has reduced emissions significantly in response to the levy.

1. Introduction

To promote efficient regulation of industrial emissions, economists have long advocated use of a pollution charge that equates industry's marginal pollution abatement cost with the social marginal damage attributable to pollution. Although pollution charges have been used in both developed and developing countries,[1] the existing evidence suggests that charges seldom if ever reflect an explicitly measured social marginal damage function. In practice, they seem to reflect an implicit 'marginal penalty function', determined by a local decision process that incorporates political factors as well as pollution damage. In regulatory equilibrium, charge rates and emissions are determined by the intersection of the marginal abatement cost and penalty functions. The divergence of 'equilibrium' charges and emissions from 'optimal' charges and emissions reflects the difference between the marginal penalty and social damage functions.

Although plentiful anecdotes illustrate the political determination of the penalty function, limited public access to regulatory information has prevented researchers from formally specifying and estimating models of regulatory equilibrium in this context. The difficulty has been compounded in developing countries, which have few operating pollution charge systems. China is a major exception, both because it has an extensive pollution charge (or levy) system and because newly available

[1] For an overview of OECD experience, see OECD (1999); for developing countries, see O'Connor (1999).

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press

Chinese data provide sufficient information for an explicit test of the equilibrium pollution model. In this paper, we specify and estimate such a model in an attempt to explain differences in pollution charges and industrial emissions across China's provinces.

China's pollution levy is one of the few economic instruments with a long, documented history of application in a developing country. In sheer magnitude, the current Chinese system may be without peer in the world. However, it has been criticized on two principal grounds. First, critics have claimed that there are marked differences in the degree of enforcement across regions. Their observations have created the impression that the current administration of the system, while improving, remains relatively arbitrary. Secondly, the incentive properties of the system have been called into question. Case studies have been used to support the claim that the levy rates are too low to have significant effects on industrial emissions (Shibli and Markandya, 1995; Florig *et al*., 1995; Yang, Cao, and Wang, 1997; Yun, 1998).

To test these propositions more systematically, we have constructed a panel of annual environmental, regulatory and socioeconomic data from 29 Chinese provinces for the period 1987–1995. Focusing on organic water pollution, we specify and estimate a model of regulation and industry response which addresses two basic questions: What explains the existing variations in effective levy rates and enforcement? Is the existing levy system effective as a pollution control instrument?

In section 2, we describe the existing levy system, effective levy rates across provinces, and variations in industry's environmental performance. We develop the equilibrium pollution model in sections 3 and 4, and present our econometric results in section 5. Section 6 provides a summary and conclusions.

2. The levy system in theory and practice

2.1. National rules

The levy system formally requires that a fee be paid by any enterprise whose effluent discharge exceeds the legal standard. China's State Environmental Protection Administration (SEPA) regulations specify variations in effluent standards by sector and fees by pollutant. With the approval of SEPA, local areas may raise both standards and fees above the nationally-mandated levels. Levies are charged only on the 'worst case' pollutant from each source.[2] To illustrate, national regulations would stipulate the following water levy for a factory j emitting N pollutants

$$L_{jM} = \text{Max}[L_{j1},...,L_{jN}] \tag{1}$$

where

$$L_{j1} = \rho_1 W_j \left[\frac{\eta_{j1} - \eta_j^*}{\eta_1^*} \right] \tag{2}$$

[2] For more discussion, see Yang, Cao, and Wang (1997), and Yun (1998).

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press

L_{j1} = Levy for pollutant 1
L_{jM} = Total levy the factory j should pay for the discharge
ρ_1 = National levy rate for pollutant 1
η_{j1} = Discharge concentration of pollutant l from plant j
η_1^* = Legal discharge concentration standard for pollutant 1
W_j = Wastewater discharge volume from plant j that exceeds concentration standards.

When $W_j(\eta_1 - \eta_l^*)/\eta_1^*$ is higher than a certain threshold, a surcharge is added to this formula and a lower charge rate ρ_1 is applied. In the case of chemical oxygen demand (COD), for example, when $W_j(\eta_1 - \eta_1^*)/\eta_1^*$ is less than 30,000 tons, ρ_1 is 0.18 yuan/ton.[3] When it is higher, ρ_1 is 0.05 yuan/ton, but a surcharge of 3,900 yuan is imposed. Different pollutants have different legal concentration standards, charge rates, and surcharge schedules. Local environmental authorities are responsible for calculating the potential levies for each pollutant discharged by each factory. The actual charge is supposed to be the highest of these potential levies. In practice, however, levies are often negotiated and local factors have a strong influence on charges.[4] We will return to this issue in our development of the equilibrium pollution model.

China's levy differs from a conventional pollution charge in two significant respects. First, restriction to the highest pollutant-specific levy penalizes only worst-case emissions from each source.[5] Secondly, the levy employs a 'markup' based on percent deviations from discharge standards for effluent concentrations: $[(\eta - \eta^*)/\eta^*]W$. This is quite different from a tax on specific pollutants: $[\eta W]$.

According to the levy collection procedure, there should be no charge on any pollution that meets the discharge standards. However, the discharge standards are very stringent; most water polluters in China are subject to levies. In 1993, for example, among the 3,000 largest industrial water polluters in China, about 90 per cent were violating the discharge standards and paying levies.

In the levy system, all polluters are required to report their emissions and the local (municipal and county) environmental authorities are

[3] We employ the ton as our unit volume measure; one cubic meter of water weighs one ton.

[4] Local collection incentives are also affected by the officially-mandated use of the levies collected. The regulations require the use of 80 per cent for grants or loans to co-finance abatement by polluters who have paid a levy and have abatement investment projects. Local environmental authorities can use the remaining 20 per cent and any other penalty fees to support their own operations. For further discussion of the allocation of levy funds, see Yun (1998) and Yang, Cao, and Wang (1997).

[5] This assumes that pollutant-specific standards, charges and surcharges reflect an appropriate assessment of damage. In the short run, all emissions with below-maximum potential levies are effectively 'free' for factories that discharge multiple pollutants. In the long run, the levy will shift across pollutants if it (along with other regulatory sanctions) provides a sufficient incentive for reducing emissions of the worst pollutants.

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press

responsible for verification and collection. The 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. Penalties are imposed 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 cent per day. Intractable disputes are resolved by the local courts or higher-level environmental authorities. Polluters are required to report increased discharges, and rebates are possible when pollution reductions are verified.

Most of the levy funds are used to promote pollution abatement. To finance new abatement projects, a polluter can apply for a grant of up to 80 per cent of its total payments to the levy system. Since 1995, some areas have changed the grants to loans in order to encourage more efficient use of the funds. The remaining 20 per cent of the funds collected, plus all relevant penalty payments, can be used by local governments to develop local environmental institutions and to finance public-sector environmental projects. This has provided strong incentives for local environmental authorities to enforce the levy system, and has significantly enhanced their capability for environmental management.

Various proposals for reforming the levy system have been advanced, and three cities have begun using levy formulas that are closer to conventional pollution charges. For more discussion of the levy system and reform proposals, see SEPA (1994), Yang, Cao, and Wang (1997), and Yun (1998).

2.2. Provincial realities

Although supervised by the central government, China's pollution levy system is implemented by the provincial[6] and municipal governments. As table 1 shows, the critics are correct when they assert that there is significant variation in implementation. The table provides provincial estimates of the real effective levy rate (or levy actually collected per unit of wastewater discharge that does not meet discharge standards), which is equivalent to L/W for the variables in equation (2)).[7] The data reveal striking differences, both across provinces and through time. In the space of six years, the effective pollution levy rate more than doubled in some areas and fell significantly in others. In general, real effective provincial levies increased during the sample period.

Inspection of provincial differences suggests that variations in the effective levy rate are far from random. Figure 1 displays their geographic distribution. In 1993, several relatively affluent, heavily industrialized coastal provinces had the highest effective levy rates, while many poorer

[6] In this paper, the term 'province' refers to provinces, autonomous regions, and municipalities that are directly affiliated with the central government.

[7] At the plant level, *W* is the total wastewater discharge that does not meet the discharge standards.

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press

Table 1. *Effective levy rate by province*

(1990 Yuan per ton)		
Province	*87*	*93*
Tianjin	0.09	0.24
Zhejiang	0.09	0.17
Liaoning	0.10	0.16
Shandong	0.15	0.16
Shanghai	0.26	0.15
Guangdong	0.07	0.13
Jiangsu	0.11	0.13
Beijing	0.12	0.12
Shaanxi	0.08	0.10
Xinjiang	0.11	0.10
Fujian	0.04	0.09
Anhui	0.05	0.09
Nationwide	0.076	0.093

interior provinces had levy rates at the bottom of the scale. Provincial and sectoral differences in discharge concentration standards may explain part of this variation, as suggested by the levy formula (2). We control for these differences in our econometric model. However, as we will show in this paper, much of the variation reflects differences in enforcement rather than differences in legal standards.

The provincial data also reveal great variation in industry's environmental performance. For 1987 and 1993, table 2 displays levels and changes of industrial emissions intensity (emissions/output) and total

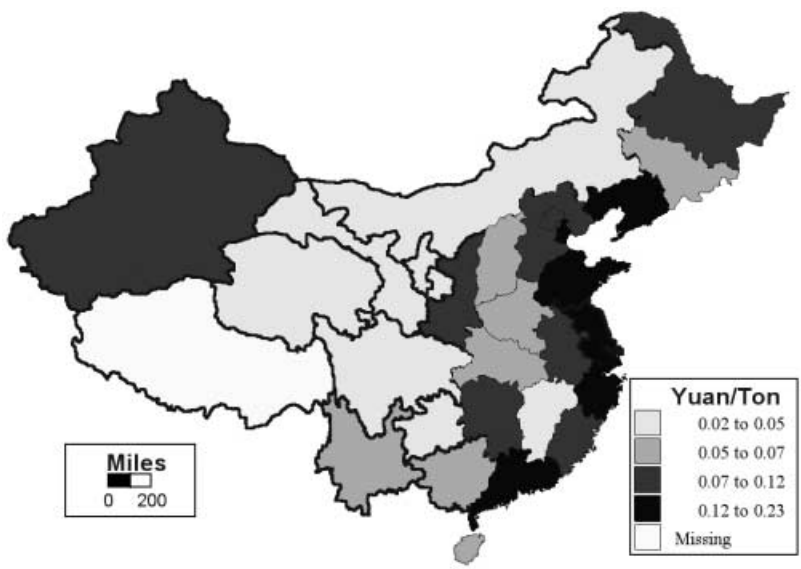


Figure 1. *Effective levy in 1993*

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press

Table 2. *Provincial pollution intensities and pollution loads, 1987–1993*

	COD intensity (tons/10 million yuan[1])			*Total COD discharge ('000 tons)*		
Province	*1987*	*1993*	*% Chg.*	*1987*	*1993*	*% Chg.*
Qinghai	51.7	6.9	−86.7	11	3	−72.7
Guangdong	102.4	19.4	−81.1	379	328	−13.5
Fujian	126.4	33.9	−73.2	228	183	−19.7
Zhejiang	106.7	38.0	−64.4	417	279	−33.1
Anhui	162.4	64.7	−60.2	402	282	−29.9
Liaoning	56.3	30.5	−45.8	462	354	−23.4
Heilongjiang	64.9	36.3	−44.0	291	220	−24.4
Henan	91.6	53.3	−41.8	335	351	4.8
Xinjiang	79.4	49.7	−37.4	71	83	16.9
Guangxi	266.8	173.7	−34.9	317	513	61.8
Beijing	25.4	17.5	−31.2	106	89	−16.0
Jiangxi	84.0	61.9	−26.3	150	181	20.7
Hainan	102.4	107.3	4.8	103	63	−38.8
Hubei	30.5	47.3	55.3	210	352	67.6
Nationwide	85.2	44.1	−48.2	7199	6222	−13.6

Note: [1] 1990 prices.

discharges of chemical oxygen demand (COD).[8] Pollution intensity varies greatly, with inter-provincial ratios as high as 25:1. For most provinces, however, the data provide striking evidence of progress in pollution control. With two exceptions (Hainan, Hubei), pollution intensity fell rapidly during the sample period. In most provinces, these reductions were sufficient to outweigh rapid increases in output, yielding significant declines in total COD emissions.

To summarize, the stylized facts offer little support for the view that the levy system is arbitrary and ineffective. While effective levies do vary greatly in China, their geographic distribution is correlated with provincial rates of urbanization and industrialization. Furthermore, recent increases in effective levies have been accompanied by large reductions in water pollution intensities and loads.

3. A model of equilibrium pollution

To analyze these patterns of co-variation, we develop a formal model of 'equilibrium pollution' in which the price and quantity of pollution are jointly determined at the intersection of environmental demand (ED) and supply (ES) functions. The ED function relates industrial pollution discharge to the local price of pollution. It reflects the economics of cost-minimizing abatement by industry, and is a mirror image of the marginal abatement cost (MAC) function featured in textbooks of environmental economics. The ES function specifies the increasing price

[8] An organic water pollutant, COD (or chemical oxygen demand), is chosen for analysis because it has been regarded as the most important water pollutant by China's environmental authorities at all levels and in all provinces.

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press

imposed by the community as pollution rises. While it reflects considerations of marginal social damage (MSD), ES is not equivalent to the textbook MSD function because it also reflects the interplay of limited information, the local economic importance of polluters, and differential ability or willingness to enforce regulatory standards. *Equilibrium pollution* (at the intersection of ED and ES) is therefore not necessarily *optimal pollution* (at the intersection of ED and MSD).

In modeling environmental supply, we focus particularly on the role of endogenous enforcement. Across provinces, regulators may differ greatly in their ability or willingness to enforce the formal regulations. In practice, regulation is almost never a 'pure' administrative process in which violations are unambiguously observed and rules are uniformly enforced. Because industry is a prime generator of income and employment, regulatory enforcement is often subjected to political pressure for leniency.[9] Even when they are unencumbered, regulators are generally reluctant to impose penalties that will bankrupt or shut down factories. They may, however, be tougher in relatively affluent regions where communities put more stress on environmental quality.

In most countries, the 'price of pollution' is not directly observable because regulation is based on enforcement of quantitative emissions standards.[10] China provides a unique opportunity to test a structural model because the price of pollution – the effective levy rate – can be measured across provinces and over time.

3.1. Industrial environmental demand

As previously noted, Chinese factories are subject to a pollution levy for emissions that exceed legal concentration standards. In our model, the expected levy reflects enforcement practice dictated by a province-specific penalty function. Cost-sensitive plants will seek to reduce pollution to the point where the expected marginal penalty is equal to the marginal cost of abatement. In a particular province, plants form expectations about enforcement of pollution regulations by observing the average experience of industrial facilities in their region.

We specify the industrial pollution intensity function as follows

$$\mu_{jr} = \gamma_0 q_{jr}^{\gamma 1} c_{jr}^{\gamma 2} \tag{3}$$

where for pollutant j and region r:

μ_{jr} = pollution discharge intensity (pollution discharge per unit of output)
q_{jr} = expected marginal discharge penalty
c_{jr} = characteristics of industries that discharge pollutant j in region r

The upper bound on γ_1 would be 0 for the case of universal compliance

[9] See Wheeler (1991).

[10] Using reduced-form estimation, one of the authors and colleagues have found evidence strongly consistent with the 'equilibrium pollution' hypothesis in Indonesia, India, Bangladesh, and Thailand. See Pargal, and Wheeler (1996); Hettige, Huq, Pargal, and Wheeler (1996); Hartman, Huq, and Wheeler (1996).

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press

with discharge standards. Since most polluters in our sample are non-compliant, however, we expect γ_1 to be negative: Pollution intensity decreases as the expected penalty (q) increases.[11] Responsiveness to the penalty is affected by local industrial characteristics (c), which determine the regional marginal abatement cost schedule for pollutant j. For γ_2, we would expect the sign to depend on the particular characteristic. For example, state-owned factories are generally less efficient and produce more waste residuals, so we would expect the parameter for state ownership to be positive. On the other hand, large plants have abatement scale economies, so we would expect a scale parameter to be negative.

To obtain the regional ***environmental demand function*** (ED) for pollutant j, we multiply pollution intensity by total industrial output for the region

$$x_{jr} = \gamma_0 q_{jr}^{\gamma 1} c_{jr}^{\gamma 2} y_r \tag{4}$$

where x_{jr} = total discharge of pollutant j in region r;
y_r = total industrial output.

3.2. Environmental supply

Several factors determine the regional ***environmental supply function*** (ES). In a well-informed community, the price of pollution should increase with the volume of emissions, since damage rises at the margin as ambient conditions deteriorate. It should also increase with local income per capita, since more affluent communities assign higher value to environmental amenities and the avoidance of health damage.[12] In China, provincial regulators often do not have precise information about ambient conditions, health damage or formal valuation techniques. However, they do have information about local emissions, income and the size of affected populations. If regulators respond to health- and income-related factors, then provincial differences in pollution, population, and per capita income should be reflected in their enforcement of the pollution levy.

Other considerations may also apply: 'Regulation is negotiation, and enforcement practice may also reflect differential information and bargaining power. For example, local perceptions of pollution problems may be affected by average education levels. Education may also affect communities' ability to organize, and bring pressure on local regulators to enforce desired levels of compliance. Local willingness to enforce more strictly may also be affected by perceptions of the potential economic consequences, particularly for communities with low levels of industrialization.[13] More heavily industrialized regions, which already enjoy a

[11] When there are no other penalties involved, the effective levy will be equal to the expected penalty in the Chinese case.

[12] Note that if environmental quality is viewed as an input in a household production function, the price of pollution may not necessarily increase with local income per capita (Maler, 1997). Our prior expectation about the positive sign of the income term reflects a model in which environmental quality enters directly into households' utility functions.

[13] The impact of stricter regulation on factory-level costs remains a controversial topic, even in OECD economies where relevant data are plentiful (Gray and

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press

strong advantage from agglomeration economies, may have much less concern about the impact of stricter regulation on industrial activity.[14] Industry's national political power may also affect local negotiations, particularly in the case of Chinese state enterprises.

To incorporate these factors, we specify the environmental supply function for region r as follows

$$q_{er} = \omega_0 \Omega f_r^{\omega 1} n_r^{\omega 2} m_r^{\omega 3} e_r^{\omega 4} i_r^{\omega 5} c_r^{\omega 6} \tag{5}$$

where q_e = expected pollution penalty rate
Ω = penalty rate prescribed by the central government
f = pollution of the local ambient environment
n = population affected by pollution
m = income
e = education
i = level of industrial development
c = relevant characteristics of industries

We project a negative impact for state ownership and positive impacts for pollution, the size of the affected population, income, education, and industrial development in the area.

4. Data sources and estimating equations

4.1. Data sources

To estimate the equilibrium pollution model, we have constructed a province-level panel database from official yearbooks available in China: The China Environment Yearbook (1987–1996); Statistical Yearbook (1987–1996), and Industrial Economy Yearbook (1987–1996). Problems with missing data have limited the estimation panel to seven years: 1987, 1988, 1989, 1992, 1993, 1994, and 1995.

4.2. Specification: environmental demand

In modeling pollution intensity at the province level, we use output shares by industry sector to control for the combined effect of sectoral differences in regulatory standards, marginal abatement costs, and emissions intensities. The significance of industry mix will depend on the degree to which sectoral regulatory standards adjust for sectoral differences in emissions intensities and abatement costs.

We cannot use provincial industrial output to capture plant-level scale economies, although prior research suggests that the latter are important determinants of pollution intensity (Wheeler *et al*., 1999). However, the available data do distinguish between production from small, medium,

Shadbegian, 1993). The issue remains largely unexplored for China and other developing countries. Without any evidence to go on, local regulators in poor regions that need industrial growth could scarcely be blamed for wariness about the economic impact of pollution regulation.

[14] See Mody and Wheeler (1992) for evidence that agglomeration economies play a powerful role in location decisions, at least for multinational corporations.

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press

and large industrial facilities. We therefore control for this factor by introducing the share of provincial output produced by large plants.[15]

We also control for state ownership, since several considerations suggest that state-owned factories may be more pollution-intensive than other facilities. First, state-owned plants may simply generate more waste residuals per unit of output because they are less efficient. Second, soft budget constraints may make them less sensitive to pollution levies. Finally, evidence from other Asian countries suggests that state-owned factories resist regulation more successfully than privately owned plants (Pargal and Wheeler, 1996). We control for these effects by introducing the provincial share of production in state-owned factories.

Pollution control instruments other than the levy may also have contributed to the reduction of pollution intensity in China. For example, previous research has found that regulatory inspections have induced significant pollution reduction by developing-country firms (Dasgupta *et al.*, 2001). We control for this factor with a measure of 'regulator intensity' for each province, defined as the total number of environmental officers divided by the total number of industrial firms.

After these adjustments, the estimating equation for the cross-provincial data set is as follows (for the rth province)

$$\log CODI_r = \alpha_0 + \sum_{k=1}^{n} \alpha_{1k} s_{kr} + \alpha_L LARGE_r + \alpha_G STATE_r + \alpha_p \log PLW_r + \alpha_o \log ENVWF_r + \epsilon_r \quad (6)$$

Prior expectations: $\alpha_L < 0$, $\alpha_G < 0$, $\alpha_P < 0$, $\alpha_O < 0$

where $CODI$ = COD intensity (COD discharge/industrial output)
S_{kr} = the industrial output share of the kth sector
$LARGE_r$ = the industrial output share of large plants
$STATE_r$ = the industrial output share of state-owned plants
PLW_r = effective pollution levy per unit of wastewater discharge
$ENVWF_r$ = regulator density (environmental officers per firm)
ϵ_r = a stochastic error term incorporating provincial components

In (6), *PLW* and *ENVWF* are endogenous policy variables.

4.3. Specification: environmental supply

On the supply side, the dependent variable is the effective levy rate, *PLW*, which is the ratio of *L* (total levy collected) and *W* (wastewater discharge that exceeds concentration standards) in the levy formula (2). We use the provin-

[15] The Chinese Industrial Economy Yearbook uses two systems for categorizing industrial facilities as large, medium, or small. For sectors with an identifiable main product, annual production capacity is used as the criterion. For example, cement plants are classifed as large if their annual production capacity exceeds 600,000 tons, medium in the range 200,000–600,000 tons, and small otherwise. For sectors with heterogeneous products, the value of fixed assets is used for size-class assignments. Plants are classified as large if their assets are valued at more than 50 million yuan, medium in the range 10–50 million yuan, and small otherwise.

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press

cial COD discharge concentration (*CODW*) to proxy the penalty factor for excess pollution (corresponding to η in (2)). In addition, we introduce sectoral output shares to allow for differentiated penalties across sectors. We proxy pollution of the local ambient environment with total wastewater density, *TWWD*, defined as total wastewater discharge per unit of land area. Our income proxy is provincial consumption per capita. We also incorporate measures of population density, education, and industry's share of provincial GDP (a proxy for industry's bargaining power). We include the output shares of state-owned plants (*STATE*) and large factories (*LARGE*) as additional controls for factors that can affect local negotiations. We expect the political insulation of state-owned plants to lower their effective levies. Large factories, on the other hand, should pay higher levies because they are more visible to the public and their total emissions may inflict greater damage in their localities.

We specify the full estimating equation as follows

$$\begin{aligned}\log PLW_r = {} & B_0 + B_1 \log CODW_r + B_2 \log TWWD_r + B_3 \log INC_r \\ & + B_4 \log EDU_r + B_5 \log IND_r + B_6 \log POPD_r + B_7 STATE_r \\ & + B_8 LARGE_r + B_9 SECTOR_r + v_r\end{aligned} \tag{7}$$

Prior expectations: $\beta_1 > 0$, $\beta_2 > 0$, $\beta_3 > 0$, $\beta_4 > 0$, $\beta_5 > 0$, $\beta_6 > 0$, $\beta_7 < 0$, $\beta_8 < 0$, $\beta_9 >$ or < 0.

where
PLW = effective pollution levy per unit of wastewater discharge
CODW = industrial COD concentration (discharge per unit of wastewater)
TWWD = wastewater discharge density (wastewater per unit of land area)
INC = per capita consumption
POPD = population density
EDU = secondary school completion rate
IND = industry share of provincial output
STATE = share of state-owned factories in industrial output
LARGE = share of large factories in industrial output
SECTOR = sector share in industrial output

In equation (7), COD concentration (*CODW*) and wastewater discharge density (*TWWD*) are both endogenous variables.

5. Econometric results

We have fitted the ED and ES equations to provincial data for 1987–1989 and 1992–1995. Both fixed-effects and random-effects estimation have been used to test the basic model, with endogenous variables instrumented.[16] The results are presented in tables 3 (ED) and 4 (ES).

5.1. Environmental demand equation

In table 3, we report estimation results for regression equation (6). The overall fits are quite good (Adjusted R^2s of 0.60 and 0.57, respectively). Results of the fixed- and random-effects models are similar.

[16] Instruments include all exogenous variables presented in equations 6–7 and year dummies.

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press

Table 3. *COD intensity equation*
(Dependent variable: log (COD/Output))

	Random-effects	*Fixed-effects*
Log (PLW)[a]	−0.349***	−0.301**
	(−3.31)	(−2.62)
Log (ENVWF)[a]	−0.105	−0.108
	(−0.74)	(−0.54)
STATE	0.966**	1.746***
	(2.00)	(2.91)
LARGE	−2.606***	−2.734***
	(−4.23)	(3.81)
Adj-R^2	0.60	0.57
N	173	173

Notes: 1 [a] denotes instrumented variables; 2 Indicated significance levels: *** 1%; ** 5%; * 10%. 3 t-values are provided in parentheses. 4 Significant sectors include textiles, power, food, building materials. Coefficients are not reported here to conserve space, but are available from the authors on request.

Table 4. *Unit levy equation*
(Dependent variable: log (Unit Levy))

	Random-effects	*Fixed-effects*
Log (CODW)[a]	1.98***	2.13***
	(4.76)	(5.08)
Log (TWWD)[a]	0.20**	−0.212
	(2.54)	(−1.34)
Log (INC)	0.57***	0.67***
	(4.75)	(4.83)
STATE	−0.74**	0.171
	(−2.06)	(0.33)
LARGE	2.68***	2.60***
	(3.97)	(3.34)
Adj-R^2	0.67	0.68
N	202	173

Notes: 1 [a] denotes instrumented variables; 2 Indicated significance levels: *** 1%; ** 5%; * 10%. 3 t-values are provided in parentheses. 4 Significant sectors include coal, ferrous metals, textiles, power, building materials, plastics, rubber, leather. Coefficients are not reported to conserve space, but are available from the authors on request.

The results suggest that Chinese industry has been responsive to the pollution levy.[17] The estimated elasticity for PLW is about −0.3 and highly significant. Since there have been large variations in the levy during the sample period, our results imply that it has played a major role in reducing industrial pollution intensity. Thus, our results strongly contradict the conventional view that the levy has not affected pollution.

[17] Two other recent studies do not find significance for pollution charges in determining pollution intensity, but both include data for only one city (Dasgupta *et al.*, 2001; Yun, 1998).

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press

The results also suggest that state ownership (*STATE*) has a significant, positive impact on pollution intensity. The output shares of state-owned factories in 1993 ranged from 31 per cent (Zhejiang) to 89 per cent (Qinghai). Since the state output share has been falling all over China, our results suggest that this transition has contributed significantly to pollution reduction.

As expected, plant scale (*LARGE*) has a large, negative, significant impact on pollution intensity. LARGE also varies greatly across provinces and through time. Large-plant shares in 1993 ranged from 15 per cent (Zhejiang) to 62 per cent (Heilongjiang). During the sample period, rapid liberalization of the Chinese economy was accompanied by a sharp rise in the output share of large factories. Across provinces, increases in the range [10–15 per cent] were not unusual. Our results suggest that this change has reduced pollution intensity significantly.

The estimated coefficient for regulator density has the expected negative sign but is not significant by the conventional criteria.[18] Among industry sectors, food and building materials have estimated pollution intensities significantly above the average, while the power sector falls significantly below it.

5.2. Environmental supply equation

In table 4, we present both fixed-effects and random-effects estimates for the environmental supply function. Collinearity is very high among our four development-related variables – per capita consumption, education, population density and industry share of GDP. Therefore, we have only been able to use per capita consumption as our proxy for relative development level.

As expected, provincial COD concentration has a significant, positive impact on the effective pollution levy. The response elasticity is about 2, suggesting that a 1 per cent increase in concentration increases the levy by 2 per cent. Results are more mixed for wastewater discharge density, which has a significant positive impact in the random-effects model but an insignificant, negative impact in the fixed-effects result.

There are similarly mixed results for state ownership, but both results support the proposition that large plants pay more than smaller ones. Our results suggest sectoral differentials as well: producers of textiles, leather, rubber, and power pay more than average, while producers of coal, ferrous metals, building materials, and plastics sectors pay less. These differences could be attributable to differential performance with respect to sectoral discharge standards, or to overall differences in sectoral bargaining power.

5.3. Shifts in pollution equilibria

Using the results in tables 3 and 4, we simulate changes in pollution equilibria to assess the relative impact of industrial environmental demand and supply variables on effective levies and emissions. For each province, we use our results for equation (6) to estimate the impact of the levy on COD intensity, and then multiply by total industrial output to estimate the

[18] Again, this result differs from the findings of Dasgupta *et. al.* (2001) for a single Chinese city.

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press

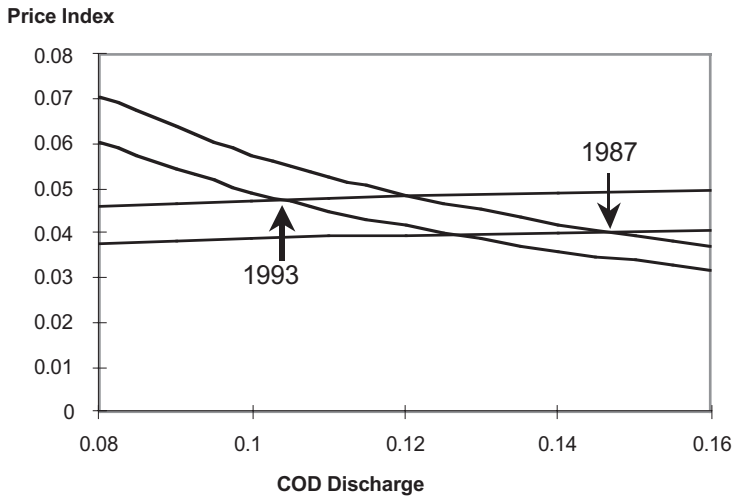


Figure 2. *Pollution equilibria in a province*

impact on total COD emissions. Using the latter, we compute the overall COD intensity (holding total wastewater discharge constant) and estimate its impact on the effective pollution levy in equation (7). Figure 2 displays simulated supply–demand intersections in 1987 and 1993 for a representative province. The *Y*-axis is scaled for the effective pollution levy, in 1990 yuan per cubic meter of wastewater. The *X*-axis is scaled for industrial COD discharge. From 1987 to 1993, the simulation suggests a downward shift in ED and an upward shift in ES. The aggregate effects are a rising pollution price and a falling pollution intensity.[19]

5.4. Summary and discussion

Our results are strongly consistent with the equilibrium pollution model, in which the price and quantity of regional emissions are jointly determined at the intersection of environmental demand and supply functions. The endogenous variables have the correct signs and a high degree of significance in both equations, and several exogenous variables have strong effects as well. Environmental demand is significantly affected by industry scale, state ownership and sectoral characteristics, while environmental supply is affected by characteristic plant scale, sector characteristics, local pollution, and per capita income. The latter two results suggest that local enforcement decisions are significantly affected by basic principles of environmental economics, as well as legally prescribed penalties for pollution in excess of legal standards.

To qualify our results, the models developed in sections 3 and 4 and estimated in this section can only approximate the complete operation of the Chinese levy system. For example, the effective levy is only the formal regulatory component of the total price of pollution faced by industrial firms. Our results provide an estimate of industry's response to this

[19] More detailed simulation results are available from the authors on request.

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press

financial charge, but the full marginal penalty function would also incorporate sources of community pressure on polluters that we cannot observe.[20] In addition, our results reflect the fact that the levy is only charged when discharges violate the standards. Within a particular province, the levy should have no effect on discharges from firms that comply with the standards. Since the available data combine discharges from compliant and non-compliant firms, our results probably underestimate the true elasticity of pollution discharge with respect to the levy. The degree of underestimation may not be large, however, since more than 90 per cent of Chinese firms were violating discharge standards during the period covered by our study.

6. Conclusions

Discussions of China's industrial pollution problem have commonly favored disaster scenarios, with widespread environmental destruction accompanying the relentless growth of highly polluting industry. These scenarios imply that China's pollution control system has been unable to cope with the challenge of rapid industrialization. A corollary view has held that administration of a key regulatory instrument – the pollution levy – has been arbitrary and ineffective.

Our analysis suggests that this scenario is mistaken, at least for water pollution control in the regulated industry sectors whose discharges are reported to SEPA. Our results do not provide a complete view of industrial water pollution regulation, because the available data do not incorporate information on discharges from many township and village enterprises. Nevertheless, they suggest that China's environmental regulators compiled an impressive record during the period 1987–1995. Despite very rapid output growth, total organic water pollution from state-regulated industries actually fell. The accompanying decline in water pollution intensity (pollution per unit of output) was very steep. Our results suggest that much of the decline was attributable to increases in the effective pollution levy, which was in turn responsive to changes in income and emissions.

We conclude that China's levy system has been working better than has been supposed, and that provincial variations in enforcement of the levy reflect significant elements of local self-interest. However, it is important to qualify our results. First, *equilibrium pollution is not optimal pollution*: the current implicit valuation of pollution damage may be inappropriately low. Variations in enforcement also seem to reflect local bargaining power. Secondly, we have no doubt that the current levy system could be significantly improved. In fact, the levy is closer to a water discharge fee than a true Pigovian tax. If some form of the latter were instituted, pollution reduction would probably be greater because all units of pollution (not just 'excess' units) would be subject to a charge.

Our results also suggest a number of lessons for pollution regulators in

[20] We have also tested a measure of regulatory enforcement and found it to be insignificant. Non-inclusion of other penalties may bias our estimated effect for the levy, but the degree and direction of the bias remain uncertain. In our simulations, we implicitly assume that other penalties remain fixed.

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press

developing societies. First, local enforcement of national standards seems likely to determine the effective 'price of pollution' in different regions. Second, enforcement reflects basic principles of environmental economics: The locally enforced price of pollution rises steadily with development, because enforcement capacity and community valuation of damage both increase. Finally, our results suggest that marginal abatement costs are modest for low-intermediate abatement levels in developing regions, because industrial emissions intensity is highly responsive to the price of pollution.

References

Dasgupta, S., B. Laplante, N. Mamingi and H. Wang (2001), 'Inspections, pollution prices, and environmental performance: evidence from China', Ecological Economics, **36**: 487–498.

Florig, H.K., W.O. Spofford Jr., X. Ma and Z. Ma (1995), 'China strives to make the polluter pay', *Environmental Science and Technology* **29**: 268–273.

Gray, W. and R. Shadbegian (1993), 'Environmental regulation and manufacturing productivity at the plant level', Center for Economic Studies, US Census Bureau, Discussion Paper No. CES 93–6.

Hartman, R., M. Huq, and D. Wheeler (1996), 'Why paper mills clean up: survey evidence from four Asian countries', World Bank, Policy Research Working Paper # 1710.

Hettige M., M. Huq, S. Pargal, and D. Wheeler (1996), 'Determinants of pollution abatement in developing countries: evidence from south and southeast Asia', *World Development* **24**: 1891–1904.

Maler, K-G. (1997), 'Environment, Poverty and Economic Growth', Annual World Bank Conference on Development Economics, 1997, World Bank, Washington, DC.

Mody, A. and D. Wheeler (1992), 'International investment location decisions: the case of US firms', *Journal of International Economics*, **3**: 57–76.

SEPA (1994), *The Pollution Levy System*, Beijing: China Environmental Science Press.

O'Connor, D. (1999), 'Applying economic instruments in developing countries: from theory to implementation', *Environment and Development Economics* **4**: 91–110.

OECD (1999), *Economic Instruments For Pollution Control And Natural Resources Management In OECD Countries: A Survey*, Paris.

Pargal, S. and D. Wheeler (1996), 'Informal Regulation of Industrial Pollution in Developing Countries: Evidence from Indonesia', *Journal of Political Economy*, **104**: 1314–1327.

Qu, Geping (1991), *Environmental Management in China*, Beijing: UNEP and China Environmental Science Press.

Shibli, A. and A. Markandya (1995), 'Industrial pollution control policies in Asia: how successful are the strategies?', *Asian Journal of Environmental Management* **3**(2).

Wheeler, D. (1991), 'The Economics of Industrial Pollution Control: An International Perspective', World Bank, Industry and Energy Department Working Paper # 60.

Wheeler, D. *et al*. (1999), *Greening Industry: New Roles for Communities, Markets and Governments*, Washington DC: Oxford University Press and World Bank.

Yang, J., D. Cao, and J. Wang (1997), 'The air pollution charge system in China: practice and reform', *Applying Market-Based Instruments to Environmental Policies in China and OECD countries*, Paris: OECD.

Yun, P. (1998), 'The pollution charge system in China: An economic incentive?', Economy and Environment Program for South East Asia (EEPSEA) research report, International Development Research Center, Ottawa.

https://doi.org/10.1017/S1355770X030024X Published online by Cambridge University Press