WPS 1630

POLICY RESEARCH WORKING PAPER 1630

Water Pollution Abatement by Chinese Industry

Cost Estimates and Policy Implications

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Data on pollution abatement costs in Chinese industry suggest that the benefits of stricter discharge standards should be weighed carefully against the costs. China's current regulatory system provides an economic incentive to abate by charging a levy on pollution that exceeds the standard. But changing to a full emissions charge system would greatly reduce total abatement costs.

The World Bank
Policy Research Department
Environment, Infrastructure, and Agriculture Division
August 1996

Summary findings

Using factory-level data provided by China's National Environmental Protection Agency (NEPA) and the Tianjin Environmental Protection Bureau, Dasgupta, Huq, Wheeler, and Zhang estimate the costs of water pollution abatement for Chinese industry. Using their econometric results, they analyze the cost-effectiveness of current pollution control policy in China — and conclude that:

- For each pollutant, marginal abatement costs exhibit great differences by sector, scale, and degree of abatement. Ratios of 20:1 in each dimension are not uncommon.
- The benefits of stricter discharge standards should be weighed carefully against the costs. For a sample of 260 factories, a shift across the existing range of standards entails a present-value difference in abatement costs of $330 million.
- Emissions charges as low as $1 a ton would be sufficient to induce 80 percent abatement of suspended solids for cost-minimizing factories. Charges of $3 a ton, $15 a ton, and $30 a ton would be sufficient to induce 90 percent abatement of suspended solids, chemical oxygen demand, and biological oxygen demand, respectively.
- The current regulatory system provides an economic incentive to abate by charging a levy on pollution that exceeds the standard. But the results of this analysis suggest that changing to a full emissions charge system would greatly reduce overall abatement costs. For the sample of 260 factories, the current overall abatement rate could be attained under a charge system with present-value savings of $344 million. At a cost equivalent to that of the current system, uniform pollution charges would produce much better environmental quality.

Approach: To measure the costs of abatement, they use joint abatement cost functions that relate total costs to treatment volume and the simultaneous effect of reductions in suspended solids, chemical oxygen demand, biological oxygen demand, and other pollutants. Tests of alternative functional forms suggests that a simple (constant elasticity) model fits the data as well as a complex (translog) models does, permitting sophisticated policy experiments with relatively simple calculations.

This paper — a product of the Environment, Infrastructure, and Agriculture Division, Policy Research Department — is part of a larger effort in the department to understand the economics of industrial pollution control in developing countries. The study was funded by the Bank's Research Support Budget under research project "The Economics of Industrial Pollution Control in Developing Countries (RPO 680-20)." Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Susmita Dasgupta , room N10-035, telephone 202-473-2679, fax 202-522-3230, Internet address sdasgupta@worldbank.org. August 1996. (23 pages)

WATER POLLUTION ABATEMENT BY CHINESE INDUSTRY: COST ESTIMATES AND POLICY IMPLICATIONS

by

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EXECUTIVE SUMMARY

In this paper, we use factory-level data provided by China's National Environmental Protection Agency (NEPA) and the Tianjin Environmental Protection Bureau to estimate water pollution abatement costs for Chinese industry. We utilize joint abatement cost functions which relate total costs to treatment volume and the simultaneous effect of reductions in Suspended Solids, Chemical Oxygen Demand, Biological Oxygen Demand and other pollutants. Tests of alternative functional forms suggest that a very simple (constant elasticity) model fits the data as well as a complex (translog) model, permitting sophisticated policy experiments with relatively simple calculations.

Using our econometric results, we analyze the cost-effectiveness of current pollution control policy in China. Our basic conclusions are as follows:

- The benefits of stricter discharge standards should be weighed carefully against the costs. For our sample of 260 factories, a shift across the existing range of standards entails a present-value difference of $330 million in abatement costs.

- Emissions charges as low as $1.00/ton would be sufficient to induce 80% abatement of suspended solids for cost-minimizing factories. Charges of $3, $15 and $30 per ton would be sufficient to induce 90% abatement of TSS, COD and BOD.

- The current regulatory system provides an economic incentive to abate by charging a levy on pollution in excess of the standard. However, our results suggest that changing to a full emissions charge system would greatly reduce overall abatement costs. For the 260 factories in our sample, the current overall abatement rate could be attained under a charge system at a reduced annual cost whose present value is $344 million. At a cost equivalent to that of the current system, uniform pollution charges could produce much higher environmental quality.

1. INTRODUCTION

Although the potential benefits of industrial pollution control are clear in many developing countries, policy makers continue to worry about the costs. It has been difficult to address this concern explicitly, because little empirical evidence has been available. In addition, information about abatement costs would be extremely useful for the design of cost-effective regulation. In this paper, we use a new plant-level database to produce such information for China. We estimate a joint abatement cost function for major water pollutants, and use the results to evaluate the economic efficiency of current regulation. We also use the econometric results to simulate the impact of an emissions charge system.

The paper is organized as follows. Section 2 provides an introduction to industrial pollution control issues in China. Section 3 uses the new dataset to develop measures of abatement and compliance for our sample of factories. In Sections 4 and 5, we specify and estimate an econometric model of abatement costs which is appropriate for simultaneous control of several pollutants. Section 6 discusses the policy implications of our results, while Section 7 summarizes the paper.

2. INDUSTRIAL POLLUTION CONTROL IN CHINA

Industrial air and water pollution in China have been major concerns for the past two decades. A recent assessment by the Chinese Research Academy of Environmental Sciences (CRAES) has identified industrial pollution as the source of approximately 70% of China's total environmental pollution. Current estimates of human health damage from urban air pollution are very high for some areas.[1]

Such high levels of damage are primarily due to the rapid growth of pollution-intensive industries, not to lack of effort by China's environmental regulators. Indeed, the pollution control program of China's National Environmental Protection Agency (NEPA) and the provincial Environmental Protection Bureaus (EPBs) is probably the most extensive in the developing world. According to CRAES (1994), pollution abatement in the past decade has been sufficient to maintain at least constant levels of industrial waste water discharge and flue dust emission from coal combustion. Total estimated emissions of suspended particulates have dropped from 13.5 million tons to 5.8 million tons. At the same time, industrial output has approximately quadrupled. The pollution intensity of output in certain key emissions categories has dropped sharply since 1985, at least in factories which are regulated by the environmental agencies.[2]

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[1] See CRAES (1994), X. Xu (1994), and Z. Xu (1995).

[2] One cautionary note is warranted here: regulatory coverage is by no means universal. It seems to be particularly sparse for Township and Village Enterprises, the fastest-growing ownership class.

This record is impressive, but several factors suggest that the next decade will pose major challenges for NEPA and the EPBs. Continued rapid decline in pollution intensity will be necessary just to stay even with the pace of industrial growth. Moreover, recent findings on pollution-related health damage suggest that considerable *improvement* in ambient quality would be appropriate. Faced with the simultaneous need to reduce pollution and increase industrial output and employment, the Chinese government has become very interested in cost-effective regulation. The current pollution control system is under scrutiny, because its peculiar mix of regulations and economic incentives bears little resemblance to a conventional emissions charge system.

NEPA regulations specify effluent standards by sector, and a schedule of fees (the pollution levy) to be paid by any enterprise whose effluent discharge exceeds the mandated standard. With the approval of NEPA, local areas may raise both standards and fees above national levels. Levies are charged only on the 'worst case' pollutant from each source.[3] This incentive system is supplemented by more traditional pollution control measures. Under the 'Three Simultaneous Steps' system, new enterprises are required to construct abatement facilities with capacity sufficient to meet the relevant effluent standards.

Chinese regulators are debating whether this mixed-instrument regime should be changed to a conventional emissions charge system. Since transition costs are likely to be high, there is strong interest in estimating the potential net gain from such a change. Theoretically, the gain could be substantial. Commonly-cited simulation results from the OECD economies suggest that total costs in a standards-based system can be several times those in a charge-based system.[4] For China, a well-informed judgment should be based on much better knowledge about actual abatement costs.

3. THE DATA

Our data are drawn from two sources: (1) the China Monitoring Station in Beijing, which monitors the 3000 factories currently rated as China's largest potential polluters; (2) the Tianjin Environmental Protection Bureau, which monitors industrial facilities in the Tianjin urban region. The available data bases include information on production, emissions by pollutant, abatement, abatement costs, and pollution-related penalties such as pollution levies, fines and compensation paid for damage. Relevant variables for the present study are summarized in Table 3.1.

For this exercise, NEPA has provided us with 1994 data for 200 factories scattered across China's urban/industrial areas. The Tianjin EPB has supplied data for 60 additional plants. The data base provides separate information for each emissions source. Many facilities have multiple sources, yielding a total sample size of 370 obsrvations. Although the data base is exceptionally complete, it records only three pollutants abated for each source. This is probably sufficient for most actual

[3] For more extensive discussion of the pollution levy system, see Wang and Wheeler (1996).
[4] See Wheeler (1992)

cases, but in theory it could cause some truncation problems. We have estimated total abatement costs for each treatment point by adding operations and maintenance expenditure to annualized services from abatement capital.[5] Data on treatment volume, influent concentration and effluent concentration are taken directly from the recorded measurements.

The current state of compliance in China is highlighted by the range of variation in abatement activity recorded in the data base. As Table 3.2b indicates, end-of-pipe abatement ranges from 0 to 100%, with median abatment of standard water pollutants (BOD, COD, TSS) in the 70-80% range and first-quartile abatement around 50%. The willingness of many plants to report non-compliant discharges to NEPA indicates that the levy system is working as intended. Excess discharges are subjected to a fee under the levy system, but they are not illegal.

China's abatement statistics compare very favorably with those of wealthier Southeast Asian economies such as Indonesia and Philippines, whose median abatement activity is closer to 50% (Hettige, et. al., 1995). Table 3.2a shows that water pollution would be much worse without existing control. Influent (pre-abatement wastestream) concentrations for most plants greatly exceed Chinese discharge standards (Table 3.3). Median influent concentrations for TSS, COD and BOD (567, 850 and 264 mg/l, respectively), are far above discharge standards for the lowest-quality water bodies in both Guangdong and Beijing. As Table 3.3b shows, median effluent concentrations are much closer to existing standards for medium-low quality water bodies, and 1st-quartile concentrations are generally in the medium-high quality range. However, a large number of plants remain out of compliance.

Tables 3.2 and 3.3 show that Chinese factory managers in polluting sectors must contend with great diversity in both process emissions and location-sensitive concentration standards. Their abatement decisions, and the overall level of abatement costs, will be significantly affected by the degree of pollution control necessary to bring their emissions into compliance with prevailing standards.

4. THE DETERMINANTS OF ABATEMENT COSTS

Traditionally, abatement cost estimates have been based on plants' reported direct costs of installing and operating pollution control equipment. Coupled with information about the benefits of reducing pollution, such cost estimates can provide a basis for setting sensible regulatory standards. Until recently, the scarcity of appropriate plant-level data has prevented detailed empirical studies of average and marginal abatement costs by pollutant.[6] Policy analyses have

[5] We have used an interest rate of 10% for this exercise.

[6] For other recent work on this issue, see Hartman, Wheeler and Singh (1995) and Mundle, et. al., (1994).

frequently developed abatement cost estimates from engineering models. However, failure to rely on behavioral data has led to considerable estimation errors.[7]

While environmental economists and policymakers have focused almost exclusively on direct abatement costs, we recognize that these provide an incomplete measure of the cost of pollution reduction. Firms can adjust to the threat of higher pollution-related costs along many dimensions, including new process technology, pollution control equipment, improved efficiency, and allocation of more resources to legal representation or negotiation. At the plant level, all these options will register as changes in the scale and mix of inputs and, consequently, total production costs. Thus, pollution control will have an impact on conventionally-defined total factor productivity (TFP) which may be significantly different than directly-reported abatement costs.[8] In this study, we focus on direct abatement costs because the available data do not permit estimation of a TFP-based cost function.

4.1 The Direct Abatement Cost Function

Industrial facilities can abate pollution by scaling back polluting activities or by diverting resources to cleanup. In either case, pollution reduction will entail costs.[9] Moreover, diminishing returns will apply: more resources will have to be devoted to cleaning up each additional unit of pollutant. Hence, the marginal abatement cost (MAC) function slopes upward from right to left as pollution falls. The position and slope of the MAC function are affected by factors such as the scale and sectoral composition of production; the average operating efficiency of the firm; the available process technologies; and the efficiency of waste treatment technologies. For any given level of pollution, more costly pollution control is associated with rightward movement of the MAC function.

Conceptually, abatement cost functions are dual to abatement functions which relate inputs of capital, labor, energy and materials to pollution reduction. Abatement processes frequently reduce more than one air or water pollutant, so joint cost function estimation is appropriate. For example, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Suspended Solids (SS) can all be reduced by treatment in common facilities. These joint equipment

[7] A useful illustration is provided by the trading price for SO_2 emissions permits under the U.S. Clean Air Act (Hamilton, 1994). Using engineering models, the U.S. Government forecast a price around \$600/ton before the trading system was instituted. In fact, permits have recently traded at prices around \$150/ton. Recent plant-level econometric work by Hartman, Wheeler and Singh (1995) on SO_2 reduction costs in the U.S. has yielded estimates much closer to the latter figure.

[8] In an econometric study of TFP impact for several U.S. industries, Gray and Shadbegian (1993) find that regulation imposes a TFP loss approximately three times higher than the reported direct cost of abatement.

[9] There is currently an important debate, initiated by Porter (1993), on whether or not firms can be made more profitable by *forcing* them to undertake pollution control activities. In a very simple static framework of analysis, Oates et al. (1993) have shown Porter's argument to be wrong, and point out that the route from pollution abatement to higher profits is much more complex than may have been thought. Ultimately, this is an empirical question.

requirements are associated with common use of skilled and unskilled labor, energy and materials.

4.2 Cost Function Specification

For k pollutants, the environmental engineering literature suggests that an appropriate joint cost function for plant i should include the following variables:

$$(4.1)\ C_i = f(W_i, \frac{E_i}{I_i}, M_j, X_i)$$

where

C_i: Total annual cost of abatement for the plant
W_i: Total annual wastewater volume
E_{in}/I_{in}: Vector of effluent/influent ratios for n pollutants, which can be interpreted either as concentration ratios or volume ratios (since waste water volume is constant across influent and effluent for each plant, it cancels out of the concentration ratio).
M_j: Vector of input prices at location j
X_i: Vector of relevant plant characteristics (sector, age, ownership, productive efficiency, etc.)

For the kth pollutant, the marginal abatement cost function is given by:

$$(4.2)\ \frac{\partial C_i}{\partial E_{ik}} = \frac{\partial f(W_i, \frac{E_i}{I_i}, M_j, X_i)}{\partial E_{ik}}$$

We exclude the vector of input prices, since appropriate cross-regional price indices are not presently available to us.[10] We specify a second-order quadratic approximation to the general cost function (or translog function) as follows:

$$(4.3)\quad \begin{aligned} \ln C = \alpha_0 + \alpha_1 \ln W + \alpha_{11} \ln W^2 + \sum_{i=1}^{N} \beta_i \ln\left(\frac{E_i}{I_i}\right) + \sum_{i=1}^{N}\sum_{j=1}^{N} \beta_{ij} \ln\left(\frac{E_i}{I_i}\right) \ln W_j \\ + \sum_{i=1}^{N}\sum_{j=1}^{N} \gamma_{ij} \ln\left(\frac{E_i}{I_i}\right) \ln\left(\frac{E_j}{I_j}\right) + \beta_{jj}\left[\ln\left(\frac{E_j}{I_j}\right)\right]^2 + \varepsilon \end{aligned}$$

[10] This exclusion increases random estimation error, but should not bias the results. As Table 5.1 shows, our results are very robust in any case.

where ε is a vector of random disturbances.

Abatement in Equation (4.3) is measured by E/I, which reflects the percent reduction in the pollutant as it passes from pre-abatement influent concentration I to post-abatement effluent concentration E. To our knowledge, such a function has not previously been fitted to data for either developed or developing countries.[11] In this paper, we fit joint abatement cost functions for four water pollutants (BOD, COD, SS, and other pollutants).

5. ECONOMETRIC RESULTS

We have fitted the general abatement cost function specified in (4.3) to sectorally-pooled data, excluding input price indices because the relevant cross-region data are not available. The results, reported in Table 5.1, include nested tests on four specifications: full translog (Equation 4.3); restricted translog (Equation 4.3 minus interactions between (E/I) ratios and treatment volume); log-log with quadratic scale effects for treatment; and simple log-log (constant elasticity). Standard F-tests on parameter restrictions (reported at the bottom of the table) suggest that the more complex, variable elasticity models do not explain observed behavior better than a simple constant-elasticity (log-log) specification. We therefore focus on results for the latter.

In the log-log regression, all the key parameters have the expected signs and high levels of statistical significance. The degree of fit to the data is quite good for a sample of this size (Adjusted $R^2 = .51$). The results suggest strong abatement scale economies, since the cost elasticity of treatment volume is approximately .4 and the standard error of the estimate is very small (t=12.39). Controlling for treatment scale, abatement cost increases with degree of abatement for all four pollutants (TSS, COD, BOD, Other).[12] All four estimates are statistically significant: BOD has the largest cost elasticity (-.33), followed by COD (-.27), TSS (-.21) and Other Pollutants (-.11). The sum of these elasticities is not significantly different from unity, suggesting that abatement cost responds unit-elastically to simultaneous reductions of all water emissions.

We have included sectoral dummy variables in the regression to control for the possibility that sector effects are significant even after influent concentrations have been accounted for. The results in Table 5.1 confirm that these effects remain highly significant. Controlling for scale and degree of abatement, Oil Refining is relatively high-cost; Food Processing and Iron and Steel are relatively low-cost.

It is also plausible to suppose that plant ownership and age could have significant positive effects on abatement costs, ceteris paribus. State-owned enterprises are often assumed to be relatively

[11] Empirical work on simpler specifications has just begun for developing countries. For recent work on abatement costs in Indian pulp mills, see Mundle (1994).
[12] The effluent/influent ratio is (1 - % abatement), so the expected sign in our regressions is negative.

inefficient, and older enterprises may use process technologies which are less well-suited for end-of-pipe abatement. We have tested both hypotheses, but have found no significant impact for either factor.

Another possible problem with our results lies in the inclusion of both Chemical Oxygen Demand and Biological Oxygen Demand in the regression.[13] Both are measures of organic water pollution (COD also incorporates the impact of other contaminants on the rate of oxidation by micro-organisms in the water). Reduction of COD always entails some reduction of BOD and conversely, so inclusion of both variables in the same regression runs some risk of 'double-counting.' To test the implications, we have run the same regression without BOD; the result is reported in Table 5.1c. It suggests a conventional effect of exclusion bias (the estimated parameter of LCOD is substantially higher), but nothing more. All other results in the regression are practically identical to the full constant-elasticity result. We conclude that inclusion of both BOD and COD in the regression is appropriate. In fact, the similarity of estimated parameters suggests that higher overall precision could be gained by constraining them to equality.

Finally, we have controlled for potential simultaneity in the joint determination of emissions and abatement costs. Since these two variables are theoretically jointly-determined in the cost-minimization exercise of the plant, the abatement parameter estimates may be biased. To check this possibility, we have re-estimated the equation using two-stage least squares. In the first-stage regressions, discharge of each pollutant (the numerator of E/I) is regressed on six variables: Total plant employment, treatment scale, influent volume for the pollutant, age of plant, a dummy variable for state ownership, and the relevant sectoral concentration standard. The results are reported in the second column of Table 5.1c. Aside from a somewhat higher estimated elasticity for COD, they are remarkably similar to the OLS results. We conclude that simultaneity is not a serious problem in this case.

To consider the policy implications of our results, we use the constant-elasticity estimates from Table 5.1b. These reflect the following total and marginal cost equations:

$$(5.1)\quad C = e^{\alpha_0} W^{\alpha_1} \prod_{i=1}^{4} \left[\frac{E_i}{I_i} \right]^{\beta_i}$$

$$(5.2)\quad \frac{\partial C}{\partial E_j} = \frac{\beta_j}{E_j} e^{\alpha_0} W^{\alpha_1} \prod_{i=1}^{4} \left[\frac{E_i}{I_i} \right]^{\beta_i}$$

[13] We are indebted to our colleague Shakeb Afsah for this point.

For a pollutant-specific emissions charge p, conversion of (5.2) to an emissions response function is straightforward under the assumption of cost minimization. For the first of four pollutants, a cost-minimizing plant should equate p_1 to (dC/dE_1), given the volume of wastewater and influent for pollutant 1. This yields the following emissions equation:

$$(5.3)\ E_1 = \left[\beta_1 e^{\alpha_0}\right]^{\frac{1}{1-\beta_1}} W^{\frac{\alpha_1}{1-\beta_1}} p_1^{\frac{-1}{1-\beta_1}} I_1^{\frac{-\beta_1}{1-\beta_1}} \prod_{i=2}^{4} \left[\frac{E_i}{I_i}\right]^{\frac{\beta_i}{1-\beta_1}}$$

In the following section, we use Equations (5.1) - (5.3) to analyze the cost-effectiveness of the current system.

6. ABATEMENT COSTS AND POLICY ALTERNATIVES IN CHINA

6.1 Marginal Cost Variations by Sector, Scale and Abatement Rate

In environmental economics, assumed variation in plant-level marginal abatement cost schedules fuels the standard critique of regulation based on uniform end-of-pipe emissions standards. The received theory suggests that use of market-based instruments, such as emissions charges or tradable permits, will realize significant efficiency gains by confronting all polluters with an identical 'price of polluting' at the margin. Of course, the theory says nothing about the actual magnitude of variations in marginal abatement costs. In practice, these have to be large enough to convince policy makers that the efficiency benefits of market-based instruments will outweigh the costs of the transition to a new regulatory regime.

Our results suggest that the magnitudes are very large. In Table 6.1 we draw on Equation (5.2) to estimate marginal costs of abatement (in annual dollars/ton) by pollutant, for plants in five sectors (Food, Textiles, Paper, Oil Refining, and Chemicals) and three abatement size classes. The impact of these variables on marginal cost is dramatically illustrated by a few comparisons. Within sectors at constant abatment rates, the MAC ratio between small and large facilities can be as high as 30:1 (e.g., TSS and COD in Food Processing). Across sectors, MAC ratios at the same scale and abatement rate can be as high as 20:1 (e.g., large-scale Food Processing and Textiles for TSS). Finally, MAC ratios in the same sector and scale class can be as high as 15:1 for 90% and 10% abatement (e.g., BOD in small-scale Paper). The implication, confirmed in Section 6.4 below, is that very large savings could be realized in an emissions charge regime which equalized the marginal 'price of pollution' across plants.

6.2 The Cost of Tighter Effluent Standards

China's current regulatory system is built around national effluent concentration standards which can be adjusted upward by local regulators with NEPA's permission. Table 3.3 illustrates the degree of variation in existing standards, by area and water quality class. In this section, we analyze the effects of variation in effluent standards using Equation (5.1). In a series of simulations, we assume that each emissions source in the sample is required to meet a broad range of effluent concentration standards for each pollutant. Given the existing sector, scale and influent concentration, we use equation (5.1) to estimate the associated abatement costs for each emissions source. We then add across sources to get total estimated abatement cost for the 260 factories in our sample.

The results are tabulated in Table 6.2. For this relatively small sample of factories, the cost implications of variable standards are obviously significant. At the bottom of the table, we use standards which reflect regulations for allowable discharges into Class D water bodies in Guangdong Province (TSS:150, COD:400, BOD:100). Total **annual** abatement costs associated with this option are $41.9 million. At Class B settings (TSS:100, COD:150, BOD: 70) the cost increases to $55.1 million. Class A settings (TSS:50, COD:50, BOD:20) escalate the costs to $74.9 million. At the accounting interest rate of 10% which we have employed for this study, the implied difference in present value between the Class A and Class D options is $330 million. This difference is large enough to warrant careful thought about the benefits associated with very strict effluent concentration standards.

6.3 The Impact of Emissions Charges

Chinese regulators are currently discussing the advisability of adopting a full pollution charge system. To assess the economics of such a system, we assume alternative schedules of uniform charges, applied throughout China.[14] At each charge rate, we apply equation (5.3) plant-by-plant to predict effluent concentration and emissions for each pollutant. We add across predicted plant-level emissions to get aggregate predicted emissions for each pollutant. Assuming constant influent concentrations and waste stream volumes, we also calculate aggregate influent for each pollutant across all factories in the sample. We then calculate aggregate percent abatement for each pollution charge level, by pollutant, along with estimated total abatement costs.

The results, presented in Table 6.3, suggest that modest pollution charges would induce very significant abatement. For Suspended Solids (TSS), $1/ton induces 84% overall abatement; the same abatement is attained for COD and BOD at $6/ton and $15/ton, respectively. As abatement moves toward OECD rates, however, MAC begins escalating rapidly. To induce 99% abatement, we estimate the necessary charges to be $45/ton for TSS and $500/ton for BOD and COD.

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[14] While we impose the assumption of uniform charges for this analysis, we would not advocate it in practice. China has great regional heterogeneity, and appropriate charges would differ across provinces. For a related analysis of provincial variations in the effective pollution levy, see Wang and Wheeler (1996).

6.4 Cost Savings with Emissions Charges

China is already operating a mixed regulatory system, with economic incentives to abate provided by the pollution levy. Wang and Wheeler (1996) find that the emissions intensity of Chinese industry has been highly responsive to variations in the effective levy across provinces and over time. It is therefore possible that the cost savings associated with movement to a conventional pollution charge system would be relatively small. On the other hand, the pollution levy penalizes only excess discharges. Up to the applicable standard, pollution is 'free' for industrial facilities, whereas pollution charges would apply to all emissions.

In Table 6.4, we assess the cost-saving implications of a shift to a pollution charge system. Adding across the 370 emissions sources in our sample, we calculate total influent and effluent for each pollutant and use the results to estimate total abatement rates. The results for TSS, COD and BOD are respectively 93%, 92% and 89%. Total associated abatement costs are $47.3 million. Using Table 6.3, we determine the charge rates which would induce equivalent abatement for each pollutant. The relevant rates for TSS, COD and BOD are respectively $4, $20 and $25 per ton. We use these rates along with equations (5.1) and (5.3) to determine emissions and abatement costs for each source under the charge regime. Adding across sources, we arrive at an estimated total abatement cost of $12.9 million -- a 73% reduction.

This result clearly highlights the impact of variability in marginal abatement costs. When industry is confronted with a uniform charge, cost-minimization shifts pollution control activity toward the least-cost abaters. The result is an **annual** difference of $34.4 million in total abatement costs for the 260 factories, which has a present value of $344 million. This is nearly identical to the cost difference estimated for a shift from Class D to Class A discharge standards in Section 6.2. The message here is clear, and quite striking: Under a uniform emissions charge regime, China could either realize very large abatement cost savings or enjoy far higher water quality at equivalent cost.

7. SUMMARY AND CONCLUSIONS

In this paper, we have used a new dataset to estimate water pollution abatement costs for Chinese industry. Using a joint cost function approach, we have developed marginal abatement cost functions which relate pollutant-specific costs to treatment volume and percent abatement for Suspended Solids, Chemical Oxygen Demand, Biological Oxygen Demand and Other Pollutants. The quality of the data has permitted testing simpler functional forms against a full translog specification. Our results suggest that a constant-elasticity model is appropriate for policy analysis.

Using the econometric results, we have analyzed the cost-effectiveness of current pollution control policy in China. Our basic conclusions are as follows:

- For each pollutant, marginal abatement costs exhibit very large differences by sector, scale and degree of abatement. Ratios of 20:1 in each dimension are not uncommon.

- The benefits of stricter effluent standards should be weighed carefully against the costs. For our sample of 260 factories, a shift of discharge standards from Class D to Class A effluent concentrations would imply a present-value difference of $330 million in abatement costs.

- Emissions charges as low as $1.00/ton would be sufficient to induce substantial abatement of suspended solids for cost-minimizing factories. Charges of $3, $15 and $30 per ton would be sufficient to induce 90% abatement of TSS, COD and BOD, respectively.

- The current regulatory system provides an economic incentive to abate by charging a levy on pollution in excess of the standard. However, our results suggest that changing to a full emissions charge system would greatly reduce abatement costs. For the 260 factories in our sample, the current overall abatement rate could be attained under a charge system at 73% lower cost. At a cost equivalent to that of the current system, uniform pollution charges could produce much higher environmental quality.

We conclude by returning to our initial question: Should China's leaders be worried about the cost of stricter water pollution control? In fact, our results suggest that more cost-effective regulatory instruments would produce considerably better environmental quality at a lower overall cost. While it seems clear that significant savings could be realized under an emissions charge system, we should note that our simulation experiment with uniform rates is purely illustrative. China is a large, diverse country with highly varied environmental, economic and social conditions. If a national emissions charge system is adopted, it would seem appropriate to give local regulators the authority to adapt charges to local circumstances.

Table 3.1

NEPA and Tianjin EPB Data on Pollution Abatement and Costs for 260 Factories (Variable Labels from Equation (4.3) in Parentheses)

Abatement Cost

Water Pollution Abatement Expenditure (**C**)
- Equipment
- Operations and Maintenance

Waste Stream Volume, Influent and Effluent*

Annual Volume of Waste Water (l.) (**W**)

Influent (**I**) and Effluent (**E**) Concentrations in Waste Water (mg/l):

- Biological Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Suspended Solids (SS)
- Other Pollutants

Table 3.2

Water Pollution Abatement in Chinese Factories

Table 3.2a: Distribution of Effluent and Influent Concentration (mg/l)

	Min	Quartile 1	Quartile 2	Quartile 3	Max
TSS Effluent	0.00	43.50	93.30	199.20	10806.00
TSS Influent	0.00	155.00	567.00	1754.00	100000.00
COD Effluent	0.00	82.14	183.78	500.00	63950.00
COD Influent	0.00	344.24	850.00	1649.25	100000.00
BOD Effluent	0.00	16.77	48.90	145.00	3886.00
BOD Influent	15.88	167.93	264.00	699.80	63075.00
Other Effluent	0.00	0.04	2.98	8.64	2500.00
Other Influent	0.00	1.73	12.00	107.43	37000.00

Table 3.2b: Distribution of Abatement (%)

	Max	Quartile 3	Quartile 2	Quartile1	Min
TSS	100.00	94.30	80.10	55.00	0.00
COD	100.00	88.20	72.60	52.70	0.00
BOD	100.00	93.10	77.60	55.80	0.00
OTHER	100.00	100.00	100.00	94.20	0.00

Table 3.3

Chinese Industrial Discharge Standards

Table 3.3a: Chinese Discharge Standards in Two Areas (mg/l)

Guangdong (1990)

Water Body Class[a]	A	B		C		D	
Discharge Scale[b]		1	2	1	2	1	2
TSS	70	100	100	200	200	200	250
BOD	30	50	60	60	70	70	80
COD	100	110	130	130	150	150	200

Beijing (1985)

Water Body Class[a]	A	B	C
TSS	30	50	80
Paper & Leather			100
BOD	5	20	60
COD	15	60	100
Paper & Leather			160

[a] Classes refer to the protection status of the receiving water body. A is for high-quality use; C-D for low-quality uses.
[b] Discharge scale is grouped into two categories: 1 = < 1000 m^3/d; 2 = > 1000 m^3/d)

Table 3.3b: Discharge Standards vs. Factory Effluent Concentrations (mg/l)

	Standards		Effluent Concentrations	
	Beijing	Guangdong	1st Quartile	Median
TSS	80 (C)	100 (B)	44	93
COD	100 (C)	200 (D)	82	184
BOD	60 (C)	60 (B)	17	49

Source: NEPA

Table 5.1

Abatement Cost Function Estimation Results

5.1a: Variable Descriptions

LTRT = Log (Volume of Wastewater Treated)

LTSS = Log (Effluent/Influent) for TSS

LCOD = Log (Effluent/Influent for COD

LBOD = Log (Effluent/Influent) for BOD

LOTH = Log (Effluent/Influent) for Other Pollutants

5.1b: Regression Results (I)

	Constant Elasticity		**Quadratic Scale**		**Partial Interactions**		**Full Translog**	
	Coefficient	**t**	**Coefficient**	**t**	**Coefficient**	**t**	**Coefficient**	**t**
Intercept	0.884**	4.90	0.849**	4.68	0.930**	4.86	0.913**	4.51
LTRT	0.408**	12.39	0.343**	6.84	0.333**	6.43	0.332**	5.37
LTSS	-0.214**	3.96	-0.208**	3.86	0.205	1.38	0.135	0.86
LCOD	-0.272**	3.08	-0.281**	3.19	-0.484**	2.54	-0.447*	1.92
LBOD	-0.330**	2.91	-0.331**	2.93	-0.222	0.83	-0.19	0.50
LOTH	-0.108**	2.21	-0.109**	2.24	-0.042	0.40	-0.038	0.33
$LTRT^2$			0.015*	1.70	0.016*	1.90	0.020**	2.06
$LTSS^2$					0.076**	3.12	0.088**	3.28
$LCOD^2$					0.031	0.46	0.030	0.42
$LBOD^2$					0.070	0.65	0.071	0.66
$LOTH^2$					0.010	0.62	0.011	0.66
LTSS*LCOD					-0.095	1.54	-0.090	1.38
LTSS*LBOD					0.194*	1.92	0.189*	1.83
LTSS*LOTH					0.093	1.24	0.105	1.37
LCOD*LBOD					-0.137	1.63	-0.132	1.53
LCOD*LOTH					-0.017	0.33	-0.031	0.44
LBOD*LOTH					-0.164	1.43	-0.163	1.41
LTRT*LTSS							0.033	1.22
LTRT*LCOD							-0.009	0.23
LTRT*LBOD							-0.005	0.09
LTRT*LOTH							-0.006	0.24
FOOD	-1.074**	3.63	-1.060**	3.60	-1.025**	3.38	-1.019**	3.31
TEXTILES	0.481*	1.87	0.469*	1.83	0.375	1.440	0.363	1.38
OIL REFINING	1.428**	4.84	1.366**	4.51	1.124**	3.690	1.044**	3.27
CHEMICALS	0.350*	1.70	0.355*	1.73	0.328	1.610	0.282	1.35
IRON & STEEL	-2.252**	4.63	-2.224**	4.58	-2.090**	4.340	-2.072**	4.28
# OF OBS.	327		327		327		327	
R^2	0.51		0.51		0.53		0.53	
CRITICAL F			2.88		2.16		1.69	

5.1c: Regression Results (II)

	OLS Without LBOD		2SLS	
	Coefficient	**t**	**Coefficient**	**t**
Intercept	0.981**	5.47	0.748**	3.71
LTRT	0.400**	12.06	0.383**	10.71
LTSS	-0.203**	3.73	-0..200**	2.78
LCOD	-0.411**	5.48	-0.485**	4.16
LBOD			-0.399**	3.05
LOTH	-0.094**	1.92	-0.098**	1.31
FOOD	-1.188**	4.01	-1.426**	4.31
TEXTILES	0.371	1.44	0.352*	1.35
OIL REFINING	1.270**	4.33	1.673**	4.78
CHEMICALS	0.240	1.18	0.352*	1.61
IRON & STEEL	-2.302**	4.68	-1.987**	4.12
# OF OBS.	327		280	
R^2	0.50		0.52	

Table 6.1

Sectoral Marginal Abatement Cost by Size of Facility
($US/ton)

Table 6.1a: Suspended Solids

	Small	Medium	Large
Food Processing			
Rate of Abatement			
0.1	0.36	0.02	0.01
0.3	0.49	0.03	0.01
0.6	0.96	0.06	0.03
0.9	5.15	0.30	0.14
Textiles			
Rate of Abatement			
0.1	0.78	0.40	0.31
0.3	1.06	0.54	0.43
0.6	2.09	1.07	0.84
0.9	11.25	5.75	4.52
Paper			
Rate of Abatement			
0.1	0.10	0.05	0.02
0.3	0.13	0.06	0.03
0.6	0.26	0.13	0.06
0.9	1.38	0.67	0.32
Oil Refining			
Rate of Abatement			
0.1	0.58	0.18	0.05
0.3	0.79	0.25	0.07
0.6	1.55	0.49	0.13
0.9	8.33	2.63	0.71
Chemicals			
Rate of Abatement			
0.1	0.12	0.04	0.02
0.3	0.16	0.05	0.02
0.6	0.32	0.10	0.04
0.9	1.70	0.54	0.23

Table 6.1b: COD

	Small	Medium	Large
Food Processing			
Rate of Abatement			
0.1	0.35	0.02	0.01
0.3	0.48	0.03	0.01
0.6	0.97	0.06	0.03
0.9	5.65	0.33	0.16
Textiles			
Rate of Abatement			
0.1	0.24	0.12	0.10
0.3	0.33	0.17	0.13
0.6	0.67	0.34	0.27
0.9	3.89	1.99	1.56
Paper			
Rate of Abatement			
0.1	0.07	0.03	0.02
0.3	0.09	0.04	0.02
0.6	0.18	0.09	0.04
0.9	1.06	0.52	0.25
Oil Refining			
Rate of Abatement			
0.1	1.47	0.47	0.13
0.3	2.03	0.64	0.17
0.6	4.13	1.31	0.35
0.9	24.10	7.61	2.04
Chemicals			
Rate of Abatement			
0.1	0.50	0.16	0.07
0.3	0.69	0.22	0.09
0.6	1.41	0.45	0.19
0.9	8.24	2.60	1.11

Table 6.1c: BOD

	Small	Medium	Large
Food Processing			
Rate of Abatement			
0.10	0.86	0.05	0.02
0.30	1.20	0.07	0.03
0.60	2.53	0.15	0.07
0.90	15.98	0.93	0.44
Textiles			
Rate of Abatement			
0.10	1.01	0.52	0.41
0.30	1.41	0.72	0.57
0.60	2.97	1.52	1.19
0.90	18.76	9.60	7.54
Paper			
Rate of Abatement			
0.10	0.26	0.13	0.06
0.30	0.37	0.18	0.09
0.60	0.77	0.38	0.18
0.90	4.88	2.38	1.15

6.1d: Treatment Scale by Sector

	Facility Scale*		
	Small	Medium	Large
Food Processing	0.16	19.55	68.90
Textiles	21.73	67.40	101.25
Paper	32.78	110.19	377.18
Oil Refining	7.65	53.60	493.43
Chemicals	1.91	13.42	56.50

* Measured in 10,000 tons of wastewater treated

Table 6.2

Abatement Cost Implications of Variable Effluent Standards: 260 Chinese Factories (SUS Million)

TSS		COD		BOD		
Standard (mg/l)	**Total Cost**	**Standard (mg/l)**	**Total Cost**	**Standard (mg/l)**	**Total Cost**	**Overall Total Cost**
50	21.1	50	35.6	20	18.2	74.9
60	20.1	60	33.9	30	15.9	69.9
70	19.4	80	31.3	40	14.4	65.1
80	18.7	100	29.4	50	13.3	61.4
90	18.0	120	27.9	60	12.5	58.4
100	17.5	150	25.8	70	11.9	55.1
110	17.0	200	23.5	80	11.4	51.9
120	15.0	250	22.1	90	10.9	48.0
130	14.6	300	20.3	100	10.6	45.5
140	14.3	350	18.8	110	10.2	43.4
150	14.1	400	17.9	120	9.9	41.9

Table 6.3
Simulation Results for 260 Chinese Factories:
Emissions Charges, Pollution Abatement, and Costs

CHARGE ($/Ton)	TSS Removal as a Percentage of Total TSS Generated	COD Removal as a Percentage of Total COD Generated	BOD Removal as a Percentage of Total BOD Generated	Predicted Total Cost (in 1,000 US $)
0.20	0.58	0.23	0.01	9351
0.40	0.72	0.35	0.06	9493
0.60	0.78	0.42	0.13	9624
0.80	0.82	0.51	0.21	9736
1.00	0.84	0.56	0.26	9831
1.20	0.86	0.60	0.30	9917
1.40	0.87	0.63	0.33	9994
1.60	0.88	0.66	0.38	10070
1.80	0.89	0.68	0.42	10148
2.00	0.89	0.70	0.45	10226
2.20	0.90	0.71	0.48	10303
2.40	0.90	0.73	0.50	10375
2.60	0.91	0.74	0.53	10443
2.80	0.91	0.75	0.55	10510
3.00	0.92	0.76	0.57	10577
3.20	0.92	0.77	0.58	10641
3.40	0.92	0.78	0.60	10704
3.60	0.92	0.78	0.61	10764
3.80	0.93	0.79	0.62	10823
4.00	0.93	0.79	0.64	10880
4.20	0.93	0.80	0.65	10936
4.40	0.93	0.81	0.66	10991
4.60	0.94	0.81	0.67	11048
4.80	0.94	0.81	0.67	11104
5.00	0.94	0.82	0.68	11161
6.00	0.95	0.84	0.72	11431
7.00	0.95	0.85	0.75	11682
8.00	0.95	0.86	0.77	11921
9.00	0.96	0.87	0.78	12151
10.00	0.96	0.88	0.80	12378
15.00	0.97	0.90	0.84	13391
20.00	0.98	0.92	0.87	14260
25.00	0.98	0.93	0.88	15042
30.00	0.98	0.94	0.90	15786
35.00	0.98	0.94	0.91	16487
40.00	0.98	0.95	0.92	17146
45.00	0.99	0.95	0.92	17770
50.00	0.99	0.96	0.93	18363
100.00	0.99	0.97	0.96	23320
500.00	1.00	0.99	0.99	45298
1000.00	1.00	1.00	0.99	62596
5000.00	1.00	1.00	1.00	141514

Table 6.4

Total Abatement Costs: Current System vs. Uniform Charges (260 Chinese Factories)

	Current Abatement Rate	Parity Charge Rate ($/ton)
TSS	0.93	4.00
COD	0.92	20.00
BOD	0.89	25.00
Total Cost ($US mil.)	47.3	12.9

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