AN ECONOMETRIC ANALYSIS ON THE ENVIRONMENTAL PERFORMANCE OF INDUSTRIAL ENTERPRISES IN CHINA

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Abstract: With econometric modeling as methodology, this paper analyzes, at the microeconomic level, about the pollution performance of Chinese industrial enterprises, based on data from the survey of the 3000 key polluters across the nation and from the investigation of about 4000 polluting sources in the country carried out by Chinese Research Academy of Environmental Sciences (CRAES) in the middle of 1990s. Pollution abatement cost function for the plants and environmental demand function are established and based on these, marginal abatement costs for various pollutants and various sectors are put forward respectively. A preliminary economic evaluation for the environmental policies such as pollution levy etc. is conducted. The main contents of the paper are (1) pollution abatement costs; (2) pollution levy and discharge intensity; (3) environmental performance of industrial enterprises; (4) conclusions.

1.0 The Pollution Abatement Cost

The pollution abatement cost and marginal abatement cost are the basic information about pollution treatment of industrial enterprises. They reflect, to a certain degree, the pollution control level of enterprises and the price of pollution.

1.1 Pollution Abatement Cost Function

Traditionally, the abatement cost function is specified mainly by the data about the cost of pollution treatment equipment and the volume of the reduction of the pollutants. This kind of abatement cost function based on engineering model was used widely. In fact, when enterprises carry out pollution abatement, they have a lot of alternatives to choose such as clean production, adopting new treatment technology and improving abatement efficiency. In other words, pollution reduction of a enterprise is closely related to the whole process of production in the enterprise. Therefore, it is cost function based on the total production factors in the enterprise that reflects its pollution abatement cost more exactly. Since data on raw material, productivity, employment and power utilization are not available, it is difficult to establish a cost function based on the total production factors involved. Therefore, a direct abatement cost function is adopted in this paper.

So far as a set of pollution treatment equipment concerned, there exists certain relationship between reduction of different pollutants. That is, when one pollutant is treated, other pollutants are treated simultaneously. For example, COD, BOD, and TSS are usually reduced at the same time by one set of wastewater treatment equipment. Accordingly, the cost function established is not for one single pollutant. Instead, it should include all the treated pollutants. For this, the following joint cost function is put forward. For the treatment with n kinds of pollutants in plant i, its abatement cost can be expressed as a function of the following variables:

$$C_i = f\left(W_i, \frac{E_{in}}{I_{in}}, X_i\right) \qquad (1)$$

Where:
C_i: Total abatement cost of the plant i
W_i: Waste water discharge volume of plant i
E_{in}: Effluent concentration of the n pollutants
I_{in}: Influent concentration of the n pollutants
X_i: Properties of the plant i (sectional category, ownership and age, etc.)

Through an approximation of a two series and second-order function to the above equation we get the following expression:

$$\ln C_i = \alpha_0 + \alpha_1 \ln W_i + \alpha_2 (\ln W_i)^2 + \sum_{k=1}^{N} \beta_k \ln\left(\frac{E_k}{I_k}\right) \ln W_i + \sum_{k=1}^{N}\sum_{p=1}^{N} \gamma_{kp} \ln\left(\frac{E_k}{I_k}\right) \ln\left(\frac{E_p}{I_p}\right) + \alpha_3 \left[\left(\ln \frac{E_k}{I}\right)\right]^2 + \varepsilon \qquad (2)$$

There are four forms[1] of the abatement cost function. The research done with about 327 plants of China by Susmita Dasgupta, *et al.*, shows that the simple constant-elasticity model not only fits the linear regression very well but also obtains highly significant and reasonable signs for the main variables. It explains the relationship among the variables well. Following their research result, the above model is further simplified and put in the form of:

$$C = e^{\alpha_0} \bullet W^{\alpha_1} \bullet \prod_{k=1}^{n} \left[\frac{E_k}{I_k}\right]^{\beta_k} \qquad (3)$$

Base on equation (3), take partial derivative of the discharge volume of pollutant 1, we have marginal abatement cost of pollutant 1:

$$\frac{\partial C_i}{\partial E_1} = \frac{\beta_1}{E_1} \bullet e^{\alpha_0} \bullet W^{\alpha_1} \bullet \prod_{k=1}^{n} \left[\frac{E_k}{I_k}\right]^{\beta_k} \qquad (4)$$

For a certain pollutant, suppose that the Effective Pollution Levy Intensity (EPLI) on it is p[2]. According to the principle of environmental economics, when the EPLI equals to the marginal abatement cost of the pollutant, a plant can achieve cost minimization.

[1] The four forms are: 1. total logarithm conversion function (two series second order approximation function); 2.limited logarithm conversion function (ignore inter-influence between water treatment amount and pollutant reduction in the two series and second order approximation function); 3.logarithm conversion and secondary influence function(ignore inter-influence between water treatment amount and pollutant reduction and the influences between different pollutants in the two series and second order approximation function); 4 simple fixed elastic model (only a one order function is considered).

[2] The levy intensity is different from pollution levy rate schedules. It is the pollution fee actual paid on the discharge of one unit pollutant, and can be viewed as the discharge price of pollutants or discharge cost.

For the first pollutant, the minimized discharge cost shall be equal to $\partial C/\partial E_1$, thus a pollutant discharge function can be obtained:

$$E_1 = \left[\beta_1 \bullet e^{\alpha_0}\right]^{\frac{1}{1-\beta_1}} \bullet W^{\frac{\alpha_1}{1-\beta_1}} \bullet p_1^{\frac{-1}{1-\beta_1}} \bullet I_1^{\frac{-\beta_1}{1-\beta_1}} \bullet \prod_{i=2}^{n}\left[\frac{E_i}{I_i}\right]^{\frac{\beta_i}{1-\beta_1}} \tag{5}$$

Above we obtained the pollution abatement cost function, the marginal abatement cost function, and the functional expression between effluent concentration and EPLI are established. In the following, the calculation of the abatement cost functions for various pollutants will be conducted using existing data.

1.2 Marginal Abatement Cost of Pollutants

Using the available data, the abatement cost functions for wastewater and waste gas are simulated respectively. The signs and significance of the main variables are reasonable in the results of regression.

Marginal Abatement Cost of Wastewater

The results of regression for wastewater abatement cost function are shown in Table 1, from which the following points are suggested:

- There is a significant positive relationship between abatement volume and abatement cost (the standard deviation is only 0.02 and t-value reaches 15.062). The water treatment coefficient is 0.3, indicating a strong scale effect in wastewater treatment.
- Abatement cost is increases with pollutant treatment efficiency, and the descending order is COD, other pollutants and TSS (the coefficient is -0.15, -0.09, -0.05 respectively).
- There is strong relationship between the wastewater treatment cost and the enterprise scale. Large enterprises has a higher treatment cost than medium enterprises and that of the latter is higher than smaller enterprises (the regression coefficient of the medium and large enterprises is 1.065 and 0.517 respectively).
- There is some relationship between wastewater abatement cost and the ownership of the plant. The regression demonstrates that state-owned and collective enterprises have lower abatement costs than other kinds of plants, such as individual enterprises, joint ventures and shared companies.
- In addition, wastewater abatement cost is closely related with the time of the installation of the treatment equipment. Generally speaking, abatement cost of old treatment equipment is higher than that of new one. It is true in our regression results (‘age’ in the equation is defined as the years from the installation of wastewater treatment equipment to the year of survey).
- Viewed from the significant sector variances in the regression, wastewater abatement costs in coal mining and processing industry, textile industry, leather industry, power industry oil processing industry coking and coal product industry, pharmaceutical industry and chemical fiber industry are higher than those of other sectors (they all have positive coefficient); and construction material industry and nonferrous product manufacturing industry have lower wastewater treatment cost than other sectors.

Table 1 Wastewater marginal abatement cost function

No.	Variables	Meanings	Coefficient	Standard deviation	t value
1	lcost	log(cost)			
2	lwtre	log(volume of waste water treated)	0.300	0.020	15.062
3	ltss	log(Effluent/Influent) for TSS	-0.048	0.030	-1.717
4	lcod	log(Effluent/Influent) for COD	-0.151	0.036	-4.219
5	loth	log(Effluent/Influent) for other pollutants	-0.091	0.027	-3.395
6	s08	Coal mining and processing	0.604	0.232	2.609
7	s22	Textile industry	0.328	0.114	2.870
8	s25	Leather, furs manufacturing	0.641	0.338	1.898
9	s33	Power and hot water	0.725	0.192	6.769
10	s34	Petroleum	1.363	0.256	5.315
11	s35	Coking, coal gas and other products	1.332	0.341	3.905
12	s38	Medical and pharmaceutical products	0.518	0.207	2.507
13	s40	Chemical fibers	0.713	0.263	2.711
14	s45	Construction and other non-metal materials	-0.600	0.201	-2.985
15	s53	Machine	-1.048	0.234	-4.487
16	a	State owned enterprises	-0.154	0.101	-1.732
17	l	Large enterprises	1.065	0.117	9.701
18	m	Medium enterprises	0.517	0.112	4.621
19	Age	Enterprise age	0.021	0.006	3.299
20	Cons	Constants	7.614	0.265	28.682
21	Samples	1174			
22	R^2	0.41			

For the reduction of pollutants, marginal abatement cost of the major pollution sectors and nationwide average abatement cost is of main concern in the study. According to the statistics of pollutant discharge in the middle of 1990s, main pollution sectors of TSS are: paper-making and paper product industry, ferrous metallurgy and press forging industry, chemical industry, ferrous metal mining and processing industry, nonferrous metals mining and processing industry, power, steam and hot water production and supply industry, and food manufacturing industry. TSS emissions of the seven sectors account for 89.0% of the national discharge (*China Environmental Yearbook, 1996*). Take a medium-sized plant as an example, we calculated the pollutant marginal abatement costs, which are shown in Figure 1. In this calculation, differences in the scope of TSS reduction rate of different industries have been taken into consideration, and the scope of reduction rate represented by the curve reflects the situation of 80% sample data. In general, a reduction rate lower than 40% can be taken as primary treatment and a reduction rate of over 50% can be taken as secondary treatment.

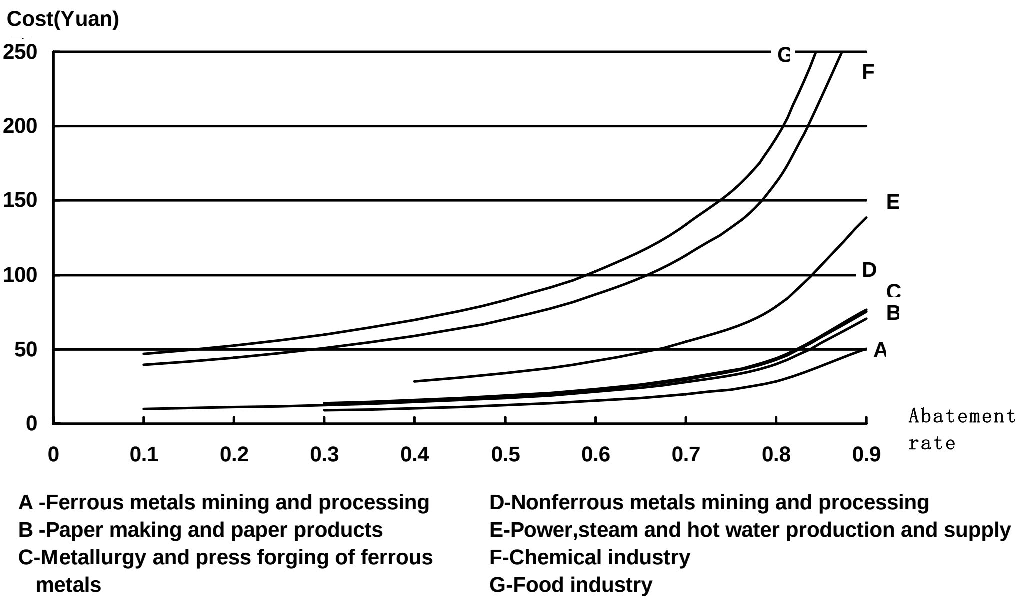


Figure 1 Marginal abatement cost of TSS of major polluting industries

Following is the sectoral characteristics of marginal abatement cost of TSS. The costs do not differ greatly in ferrous metals mining and processing industry, paper-making industry, ferrous metallurgy and press forging industry and nonferrous metals mining and processing industry. Marginal abatement cost of electric power industry is a bit higher than that of the other four sectors. But chemical industry and food manufacturing industry have much higher marginal abatement costs than other sectors.

According to a statistic calculation based on the sample points selected by the Chinese Environmental Monitoring Center(CEMC) and the CRAES, TSS reduction rate in about 70% enterprises reached the reduction rate of 70%. At such a level, the marginal cost in the ferrous metal mining and processing industry, which has the minimum reduction cost, is 20yuan/ton; and that of food manufacturing industry, which has the maximum reduction cost, is 133.8yuan/ton.

Similarly, statistics of pollutant emission volume in the middle of 1990s indicated the main sectors of COD pollution: paper-making and paper product industry, food manufacturing industry, chemical industry, pharmaceuticals industry, drink manufacturing industry, textile industry and ferrous metallurgy and press forging industry. COD emission of the seven sectors accounts for 88.4% of the over all emission (*China Environmental Yearbook,, 1996*). With the same assumptions as for TSS, differences scopes of reduction rate in different sectors represented by the curve reflects the situation of 80% sample data, the marginal abatement cost of COD of respective pollution sector is found and illustrated in Figure 2.

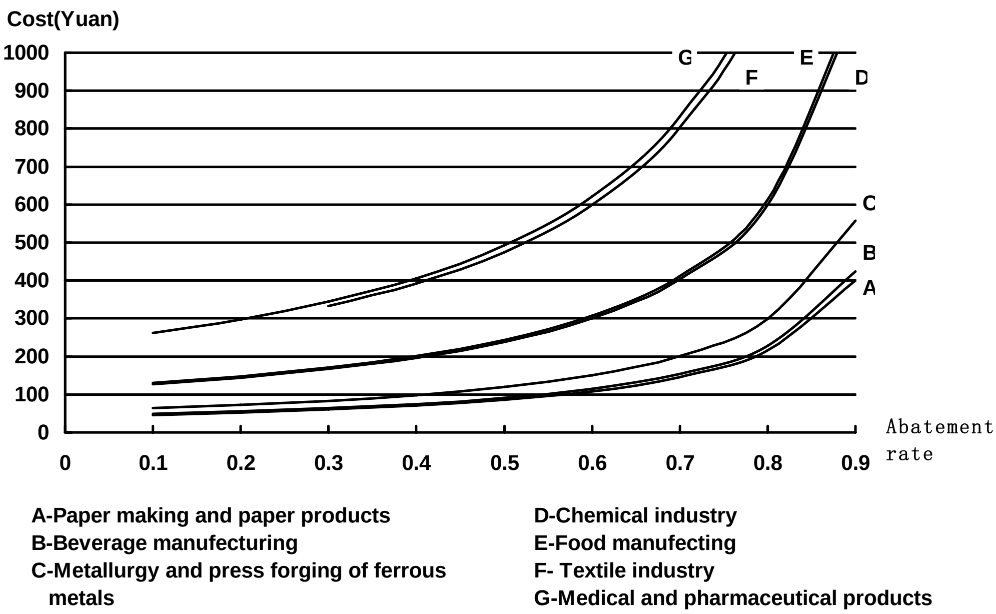


Figure 2 Marginal abatement cost for COD in major polluting industries

The sectoral characteristics of COD marginal abatement cost are identified as follows. Cost is the lowest in paper-making and paper product industry and the highest in pharmaceuticals industry. The marginal cost rises with the degree of abatement. But the magnitudes of rising are small of the former four pollution sectors. The latter three sectors not only have relatively high marginal abatement cost, but also their magnitudes of rising are big. It is clear that COD abatement of the three sectors is relatively harder and requires a lot of fund.

Also as the indicated by the statistic calculation on samples selected by the CEMC and CRAES, enterprises of China that achieved the COD reduction rate of 55% amount to 70% of all enterprises. At such a level, the marginal cost in the paper making industry, which has the minimum reduction cost, is 100yuan/ton; and that of pharmaceutical industry, which has the maximum reduction cost, is around 550yuan/ton.

Based on the pollutant reduction cost function we developed, the comparison of TSS and COD reduction cost has been done. However, it should be pointed out that the data of samples we used for establishing the cost function are only end-pipe treatment cost, and do not cover cost associated with pollutant treatment before the treatment facilities. Therefore for some industries, it is possible that such figures may be lower than actual cost. Take paper making industry as an example, with respect to the data on treatment cost, the cost in alkaline recycling is not included. To clarify this issue, we conducted a statistic investigation in over 10 paper making factories along the Huaihe River. Based on the calculation of the investigation, alkaline recycling cost amounted to 1495yuan/ton COD. Therefore, if alkaline recycling cost is considered, the marginal treatment cost of COD in the paper making industry will be significantly larger. The same problem exists in the marginal treatment cost calculation of TSS.

Waste Gas Marginal Abatement Cost

The regression results of waste gas abatement cost are shown in Table 2 below.

Table 2 Abatement cost function of air pollutants

No.	Variables	Meanings	Coefficients	Standard deviation	t value
1	lcost	log(cost)			
2	latre	log(volume of waste air treated)	0.399	0.019	20.993
3	lso2	log(Effluent/Influent) for so_2	-0.124	0.048	-2.587
4	lsmdu	log(Effluent/Influent) for smoke and dust	-0.076	0.019	-3.999
5	loth	log(Effluent/Influent) for other pollutants	-0.0002	0.055	-0.004
6	s10	Ferrous metal mining and processing	-1.335	0.519	-2.570
7	s34	Petroleum processing	2.307	0.423	5.455
8	s36	Chemical industry	0.855	0.218	3.928
9	s38	Medical and pharmaceutical industry	1.509	0.488	3.094
10	s45	Construction materials and other non-metal products	-0.993	0.199	-4.990
11	s48	Smelting and processing of ferrous metals	0.610	0.219	2.779
12	s49	Smelting and processing of nonferrous metals	2.464	0.261	9.449
13	s53	Machinery	1.570	0.784	2.001
14	staff	Number of workers in enterprise	-7.58×10^{-6}	3.00×10^{-6}	-2.525
15	b	Collective-owned enterprises	-0.281	0.149	-1.881
16	c	Sole foreign-owned, joint venture and cooperative, and share holding enterprises	1.151	0.456	2.522
17	cons	constants	5.143	0.393	13.074
18	No. of Samples	1077			
19	R^2	0.5672			

The following conclusions are deprived from the regression result:

- Waste gas abatement cost rises with the treated volume and the abatement efficiency.
- Different from wastewater treatment, air pollution abatement cost is negatively related with plant scale. It declines gradually with the increasing of the number of the staff and labor in the plant. This relationship, though, is weak (the coefficient of ‘Staff’ is $-7.58*10^{-6}$).
- Similarly, atmospheric pollutant abatement cost is related with the ownership of the plant. The regression results show that it is lower in collectively-owned plants than in the other kinds of plants. Joint ventures and stock companies have higher abatement costs than other kinds of plants.
- Air pollution treatment cost also shows some sectoral characteristics. It is lower than the other sectors of the country in ferrous metals mining and processing industry and construction material product industry. It is higher than national average in oil processing industry, chemical industry, pharmaceuticals industry, ferrous metallurgy and press forging industry, nonferrous metallurgy and press forging industry and machinery manufacturing industry.

According to the statistics in the middle of 1990s, the main pollution sectors of smoke and dust are: electric power industry, construction material and non-metals product industry, chemical industry, ferrous metallurgy and press forging industry, food processing industry and paper-making industry. The seven sectors discharge 84.4% of the overall smoke and dust emission. Figure 3 illustrates marginal abatement cost of these sectors (differences scope of reduction rate reflects the situation of 80% sample data).

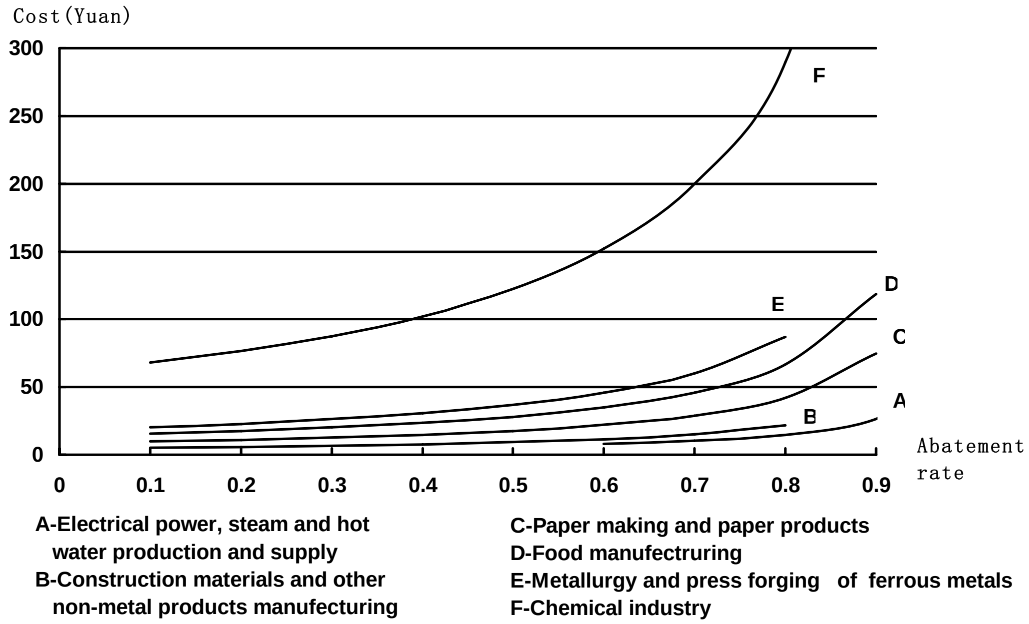
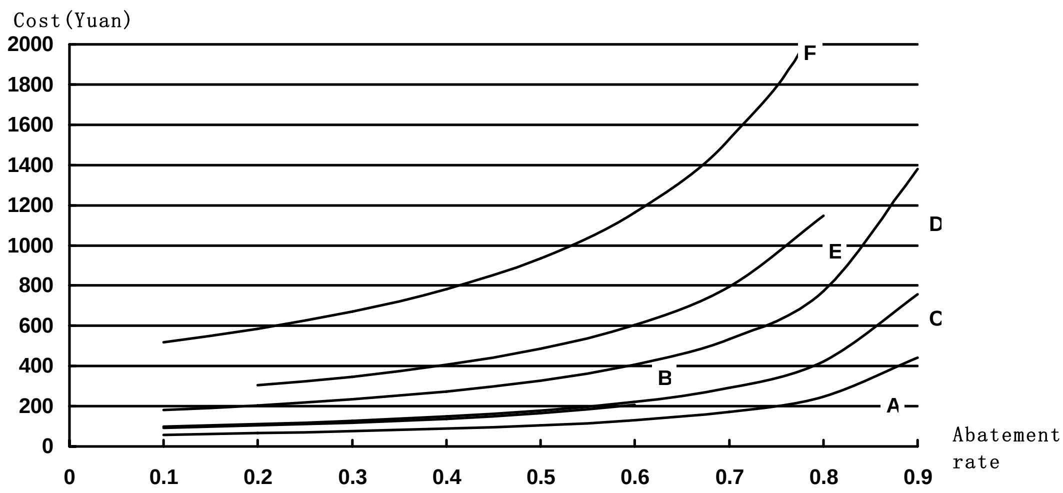


Figure 3 Marginal abatement cost of smoke and dust in the major polluting industries

The sectoral characteristics of smoke and dust marginal abatement cost are shown as follows. The marginal cost is the highest in chemical industry, which is about 3 times higher than that of other sectors. The lowest level is in electric power, steam and hot water production and supply industry, which is only one twentieth of that in chemical industry. The second lowest level is in construction material and nonferrous metals product industry. These two sectors are the best objects of industrial smoke and dust reduction because of their particularly low marginal abatement cost. The causes of the obvious low abatement cost in the power industry is due to the significant scale impact of the industry, which has a large pollutant reduction scale.

Based on the analysis of the sample data, around 70% of the enterprises of the whole country achieved a reduction rate of 90%. At such a level, the marginal cost in the power industry, which has the minimum reduction cost, is 26.3yuan/ton; and that of chemical industry, which has the maximum reduction cost, is around 515.8yuan/ton.

The statistics of the middle of 1990s show that the main sectors of SO_2 emission are electric power-steam-hot water production and supply industry, construction material and non-metals product industry, chemical industry, ferrous metallurgy and press forging industry, nonferrous metallurgy and press forging industry, and food processing industry. These sectors discharge 82.5% of the total SO_2 emission. Figure 4. shows marginal abatement cost of these sectors.



A-Electric, steam and hot water production and supply
B-Construction materials and other non-metal products
C-Metallurgy and press forging of ferrous metals
D-Chemical industry
E-Food manufacturing
F-Metallurgy and press forging of nonferrous metals

Figure 4 Marginal abatement cost of SO_2 in the major polluting industries

Following are the sectoral characteristics of SO_2 marginal abatement cost. Abatement cost of SO_2 is much higher than that of industrial smoke and dust. Take electric power industry as an example. The marginal abatement cost of SO_2 is about 17 times that of smoke and dust. For ferrous metallurgy and press forging industry and food manufacturing industry, the marginal costs of SO_2 are at the higher level. Electric power, steam and hot water production and supply industry has the lowest SO_2 marginal abatement cost, followed by construction materials and other non-metal products industry. Compared with other pollutants, marginal abatement costs of SO_2 differ greatly among sectors. For 70% abatement rate, the cost of ferrous metallurgy and press forging industry is 9 times that of electric power industry.

In addition, judged from the sample data studied, the major SO_2 samples are enterprises with industrial process SO_2 emission and treatment. Therefore, the marginal SO_2 reduction cost figure we got mainly reflects the abatement cost of industrial process SO_2 emission. Based on our analysis, there is no specific treatment facility in the sample data of power industry, and thus the sampling data mainly represent the ratio of SO_2 reduction cost in smoke reduction processes. If specific treatment facilities are considered, the figure of marginal SO_2 treatment cost will change to a certain degree.

1.3 Discharge Standards and Abatement Costs

Using formula (3), we calculated the cost for the achievement of different pollutant discharge concentration based on current average level of wastewater treatment volume and average pollutant concentration of the influent.

Base on the *Comprehensive Standards for Wastewater Discharge* (GB8978-1996) practiced in China, secondary standard for TSS is 200mg/l, and secondary standard for COD is 150mg/l. Based on such standards, the cost for achieving secondary standard for TSS and COD is 386,000 Yuan.

In a similar way, assuming that the incoming concentration of smoke and SO_2 is constant (take the average value of all samples), we can use formula (3) to get the pollutant treatment cost under different air pollutants emission standards.

Base on *Comprehensive Standards for Air Pollutants Emission*, smoke emission standard is 150mg/m^3, and SO_2 emission standard is 700mg/m^3. To achieve such standards, the cost for enterprises will amount to 427,000yuan. It should be noted that the level for SO_2 emission reduction in China is fairly low, in the sample investigated, only a very limited number of enterprises adopted specific control technologies. Thus the calculation of SO_2 reduction cost is obviously low, and the air pollution abatement cost of using specific SO_2 control technologies achieving the standards above will be far more than the cost above-mentioned.

It can be seen from the analysis above that under current situation, the cost for the enterprises to achieve secondary wastewater discharge standards and current standards for air pollutants will be 813,000yuan, accounting for 2.6% of the average product value of the sample enterprises. This is to say that to achieve the current standards in pollutant discharge, enterprises must take 2.6% of their product value for pollution mitigation.

1.4 Effective Pollution Levy Intensity and Abatement Costs

In order to illustrate the effects of EPLI on pollution control, a fixed volume of treated wastewater and air and a fixed influent concentration are assumed. The effluent concentrations of various pollutants at various EPLI can be obtained by applying equation (5). The corresponding abatement rate and cost are deprived. Figure 5 illustrates the results.

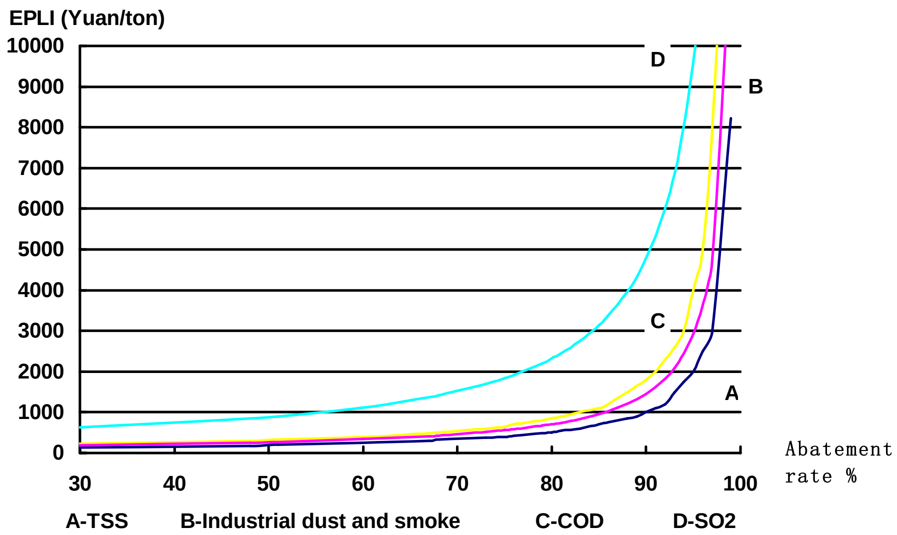


Figure 5 Relationship between EPLI and abatement rate

It is clear that the effects of EPLI on abatement rates are significant while they are not so significant on abatement costs. Take TSS abatement as an example. At TSS EPLI of 150 yuan/ton, its abatement rate is 16% and its abatement cost is 270 thousand yuan. At EPLI of 500 yuan/ton, its abatement rate is 73%, which is a big increase, as compared with the previous rate while its abatement cost is 288 thousand yuan, which is not a significant change comparing with the previous cost. Therefore, pollution levy is an effective instrument to control pollution emission.

2.0 Pollution Levy and Emission Intensity

Environmental demand function reflects the impacts of enterprise behavior on the environment, and the enterprise response to environmental policies. It is aimed to establish a connection between enterprise and the environment policy and explain the environmental behavior of the enterprises. Therefore, the variant contained in the function will mainly reflect information on related enterprises and environmental policies.

Pollution levy is a major economic instrument in environmental management of China, and is also the only environmental policy variant that has data support in establishing environmental demand function. Therefore, we mainly analyzed the impacts of pollution levy on the discharge intensity.

2.1 Environmental Demand Function

Total pollution control cost of a enterprise decides its demand to environment, and also effects the environmental price or discharge price. So developing the environmental demand function should start from the analysis of pollution control cost. Pollution levy and treatment cost are two main components of pollution control cost for enterprises in China.

The current collecting system in China is single factor, over standard discharge levy (i.e., always charge the one pollutant that is in excess of the standard by the largest amount). For plant i, assume discharge of pollutant k is excessive, the total levy of the ith plant is:

$$L_i = p_k \bullet \left[\frac{E_k - S_k}{S_k} \right] \bullet W_i = p_k \bullet \left[\frac{E_k}{S_k} - 1 \right] \bullet W_i = p_k \bullet \left[\frac{\eta_k}{S_k} - w_i \right] \bullet Q_i \tag{6}$$

Where,

L_i: The discharge levy of the ith plant

P_k: EPLI of pollutant k

E_k: Effluent concentration of pollutant k

S_k: Discharge standard of pollutant k

W_i: Emission volumes of the excessive pollutant of plant i (such as wastewater or waste gas)

Q_i: Production values of plant i

w_i: Wastewater or waste gas discharge intensity of per unit production value, $w_i=W_i/Q_i$

η_k: Pollutant discharge intensity of per unit production value, $\eta_k=E_k*w_i$

According to the research done with sample of China enterprises by Susmita Dasgupta, *et al.*, the abatement cost of k pollutant in plant i is shown as follows (Susmita Dasgupta,1996):

$$C_i = \alpha_0 \bullet W_i^{\alpha_1} \bullet \left\{ \left[\frac{E_k}{I_k} \right]^{\beta_k} - 1 \right\} = \alpha_0 \bullet \left(w_i \bullet Q_i \right)^{\alpha_1} \bullet \left\{ \left[\frac{E_k \bullet w_i}{I_k \bullet w_i} \right]^{\beta_k} - 1 \right\}$$

$$= \alpha_0 \bullet \left(w \bullet Q \right)^{\alpha_1} \bullet \left\{ \left[\frac{\eta_k}{\lambda_k} \right]^{\beta_k} - 1 \right\} \tag{7}$$

Where:
I_k: Influent concentration of pollutant k
λ_k: Generation intensity of pollutant k

Thus the total cost of pollution control of plant i is:

$$T_i = L_i + C_i = p_k \bullet \left[\frac{\eta_k}{S_k} - w \right] \bullet Q + \alpha_0 \bullet \left(w \bullet Q \right)^{\alpha_1} \bullet \left\{ \left[\frac{\eta_k}{\lambda_k} \right]^{\beta_k} - 1 \right\} \tag{8}$$

To minimize T_i, plant i should choose η_K such that :

$$\frac{\partial T_i}{\partial \eta_i} = 0 \tag{9}$$

For the ith plant, its treatment cost minimizing discharge intensity (environmental demand function) is as follows:

$$\eta_k = \left(-\alpha_0 \bullet \beta_k \right)^{\frac{1}{1-\beta_k}} \bullet Q^{\frac{\alpha_1 - 1}{1-\beta_k}} \bullet w^{\frac{\alpha_1 - 1}{1-\beta_k}} \bullet \lambda_k^{\frac{\beta_k}{\beta_k - 1}} \bullet S_k^{\frac{1}{1-\beta_k}} \bullet p_k^{\frac{1}{\beta_k - 1}} \tag{10}$$

The above equation shows that discharge intensity is related with the production value of the plant, pollution generation, wastewater and waste gas abatement, discharge standards and EPLI.

Water environmental demand function

The environmental demand functions of TSS and COD are simulated based on the data from CRAES. The results of TSS are shown in Table 3. The following conclusions are drawn from the regression results.

- There is a very significant negative correlation between TSS discharge intensity and levy (t-value is -15.638), showing powerful reduction effects of emission levy on pollution discharge. However, it should be noted that due to the limits of the policy variant in the model, a magnification effect may be in existence.
- The sectoral characteristics of TSS discharge intensity are as the follows. TSS discharge intensities in textile industry and machinery manufacturing industry are lower than the average of the other sectors; The intensities in nonferrous metals mining and processing industry, drink manufacturing industry, paper making industry, electric power industry, and chemical industry, are higher than that of the other sectors. It is the highest in paper making and paper product industry, with a

regression coefficient of 2.112. This shows that papermaking industry is the major sector of TSS pollution.

- There are relationships between TSS discharge intensity and plant size. TSS discharge intensities of medium-sized plants are lower than that of large and small plants (the regression coefficient is negative).
- The geographical property of TSS discharge intensity is that it is lower in western area than that in other parts of the nation. This may related to the backward economy in western area.
- The regression result does not have variant to reflect enterprise ownership, indicating there is no strong co-relationship between enterprise ownership type and TSS discharge intensity.
- The regression result doesn't indicate a significant relationship between TSS discharge standard and discharge intensity.

Table 3 TSS environmental demand function

No.	Variables	Meanings	Coefficient	Standard deviation	t value
1	ltssint	TSS discharge intensity(volume of TSS emission/output value)			
2	ltsslevy	Effective TSS charge(amount of TSS charge/volume of TSS emission)	-0.720	0.046	-15.638
3	s11	Nonferrous metal mining and processing	2.411	0.953	2.530
4	s19	Beverage manufacturing	1.746	0.812	2.150
5	s22	Textile industry	-0.933	0.540	-1.726
6	s28	Paper making and paper products	2.112	0.442	4.775
7	s33	Electric, steam and hot water production and supply	1.917	0.504	3.801
8	s36	Chemical industry	0.772	0.423	1.826
9	s53	Machinery industry	-1.276	0.731	-1.745
10	fw	Far Western Region[3]	-1.395	0.631	-2.213
11	m	Medium scale enterprises	-0.631	0.274	-2.302
12	cons	Constants	1.720		
13	No. of samples	245			
14	R^2	0.5564			

The regression results of COD environmental demand function based on CRAES data are listed in Table 4. The following conclusions can be concluded from the regression result.

[3] Note: The region variable in the equation is according to the World Bank Standard in which China is divided into 7 regions:
Far West region: Xinjiang, Tiebet, Qinghai, Gansu, Ningxia;
North Hinterland region: Heilongjiang, Jilin, Internal Mongolia, Shangxi. Shaanxi;
South Hinterland Region: Sichuan, Guizhou, Yunnan, Guangxi;
Central Core Region: Henan, Anhui, Jiangxi, Hubei, Hunan;
North Coast Region: Liaoning, Hebei(including Beijing and Tianjin), Shandong;
East Coast Region: Jiangsu (including Shanghai), Zhejiang
South Coast Region: Fujian, Guangdong, Hainan.

- Pollution levy system effectively reduces COD discharge. There is a significant negative relation between them. But it should be noted there might be a magnification effect due to the limit of policy variant.
- For the sectoral characteristics of COD discharge intensity, the sectors whose discharge intensities are under national average (the discharge coefficient is negative) include: tobacco industry, textile industry, sewing industry, rubber manufacturing industry, plastic manufacturing industry, ferrous metallurgy and press forging industry, nonferrous metallurgy and press forging industry, metal product industry, machinery manufacturing industry, communication and transportation equipment manufacturing industry, and electronics and telecommunication equipment manufacturing industry. Nonferrous metallurgy and press forging industry has the lowest discharge intensity (regression coefficient is -3.772). The discharge intensities of drink manufacturing industry, timber processing and bamboo, cane, palm fiber, leather product industry, and paper making and paper product industry are higher than that in other sectors, during which it is especially high in paper making and paper product industry, with a t-value of 9.336.
- COD discharge intensity has some relationship with enterprise scale. COD discharge intensity is lower in large enterprises than that of medium and small enterprises.
- For the geographical characteristics of COD discharge intensity, they are higher in northern and southern hinterland, central area, and northern coastal and eastern coastal area than that in western area and southern coastal area. Eastern coastal area has the highest intensity, followed by central area and northern hinterland.
- The regression result doesn't indicate a significant relationship between COD discharge intensity and enterprises ownership. The enterprise ownership variant is not significant in the regression result.

Table 4 COD environmental demand function

No.	Variables	Meanings	Coefficient	Standard deviation	t value
1	lcodint	COD emission intensity(volume of COD emission/output value)			
2	lcodlevy	Effective COD charge(amount of COD charge/volume of COD emission)	-0.759	0.023	-33.502
3	s19	Beverage manufacturing	0.601	0.211	2.850
4	s20	Tobacco processing	-2.805	0.613	-4.573
5	s22	Textile industry	-0.561	0.151	-3.721
6	s24	Sewing industry	-2.678	0.866	-3.093
7	s26	Timber processing, bamboo, cane, palm fiber and straw products	1.072	0.403	2.663
8	s28	Paper making and paper products	1.623	0.173	9.366
9	s41	Robber products	-1.252	0.549	-2.28
10	s43	Plastic products	-1.411	0.707	-1.995
11	s48	Smelting and processing of ferrous metals	-1.098	0.451	-2.436
12	s49	Smelting and process of nonferrous metals	-3.772	1.22	-3.088
13	s51	Metal products	-1.957	0.656	-2.981
14	s53	Machinery industry	-1.606	0.310	-5.171
15	s56	Transportation equipment manufacturing	-2.124	0.415	-5.114
16	s60	Electronic and telecommunication manufacturing	-1.872	0.467	-4.007
17	l	Large scale enterprises	-0.444	0.123	-3.606

18	nh	Northern Hinterland Region	0.772	0.211	3.655
19	sh	Southern Hinterland Region	0.611	0.219	2.789
20	cc	Central Core Region	0.787	0.203	3.870
21	nc	Northern coastal Region	0.512	0.189	2.707
22	ec	Eastern coastal region	0.794	0.198	4.011
23	cons	Constants	1.730		
24	No. of samples	1053			
25	R^2	0.6164			

Atmospheric environmental demand function

The regression results of smoke and dust environmental demand function are listed in Table 5.

Table 5 Environmental demand function of smoke and dust

No.	Variables	Meanings	Coefficient	Standard deviation	t value
1	lsdint	Emission intensity of smoke and dust (amount of smoke and dust emission/output value of enterprises)			
2	lsdlevy	Effective smoke and dust charge(amount of smoke and dust charge/volume of smoke and dust)	-0.491	0.028	-17.277
3	s16	Tap water production and supply	3.695	1.570	2.354
4	s20	Tobacco processing	-1.853	0.791	-2.342
5	s22	Textile industry	-0.599	0.244	-2.454
6	s28	Paper making and paper products	0.726	0.303	2.398
7	s33	Electric, steam and hot water production and supply	2.386	0.290	9.950
8	s36	Chemical industry	0.427	0.207	2.062
9	s45	Construction material and other non-metal products	0.570	0.209	4.639
10	s53	Machinery industry	-0.675	0.198	-3.414
11	s56	Transportation equipment manufacturing	-0.919	0.302	-3.046
12	l	Large scale enterprises	-1.364	0.162	-8.431
13	m	Medium scale enterprises	-0.613	0.144	-4.260
14	nh	Northern Hinterland Region	0.406	0.152	2.673
15	sh	Southern Hinterland Region	0.438	0.172	2.554
16	ec	Eastern coastal region	-0.819	0.235	-3.483
17	cons	Constants	2.085		
18	No. of samples	668			
19	R^2	0.4973			

The following conclusions can be concluded from the regression result.

- There is a significant negative relationship between smoke and dust emission intensity and their EPLI (the coefficient reaches -0.491, and t value is -17.277), and with the increase of pollution levy on smoke emission, smoke emission intensity decrease gradually. This suggests a positive role of emission levy on smoke and dust emission abatement.

- Now examine the sectoral characteristics of smoke and dust emission intensity. The discharge intensities in tobacco industry, textile industry, machinery manufacturing industry, and communication and transportation equipment manufacturing industry are lower than national average (the regression coefficient is negative). Among them, tobacco industry has the lowest intensity (the regression coefficient is -1.853 and t-value is -2.342); The intensities of tap water production and supply industry, paper making industry, electric power industry, chemical industry, construction material manufacturing industry are higher than that of the other sectors. Among them it is particularly high in electric power industry, which has a regression coefficient of 2.386 and a t-value of 9.950.
- Smoke and dust emission intensity is also related with the size of plants. It rises gradually with the decline of plant scale. This reflects the scale effect of smoke reduction in enterprises.
- There are obvious geographical characteristics of smoke and dust discharge intensity. It is lower than other parts in the nation in eastern coastal area, including Jiangsu, Shanghai and Zhejiang provinces; while it is higher in northern hinterland and southern hinterland, implying higher intensities in the hinterland.
- There is no obvious co-relationship between the enterprise ownership and smoke emission intensity.

From the point of view of the factories, since SO_2 is not charged nationwide, the measuring and reporting of its emission volume are far from complete. From the point of view of discharge levy policies, since SO_2 emission levy system is still in trial at present in China, researches and perfection of the running mechanism and the impacts of levy on pollution reduction are needed. These are the uncertain factors about the policy variables of discharge levy, and make it hard to establish SO_2 environmental demand function. However, the samples of 231 plants in the study ensure that the regression results can illustrate basically the inter-relationships between SO_2 emission intensity and SO_2 levy. The regression results of SO_2 environmental demand function are listed in Table 6.

Table 6 SO_2 environmental demand function

No.	Variable	Meanings	Coefficient	Standard deviation	t Value
1	lso2int	SO_2 discharge intensity(volume of SO_2 discharge /output value)			
2	lso2levy	Effective SO_2 charge(amount of SO_2 charge/volume of SO_2 emission)	-0.730	0.050	-14.692
3	s19	Beverage manufacturing	-1.101	0.633	-1.740
4	s20	Tobacco processing	-1.707	1.020	-1.673
5	s33	Electric, steam and hot water production and supply	1.504	0.730	2.061
6	fw	Far Western Region	0.550	1.025	3.059
7	sh	Southern Hinterland region	0.529	0.238	2.224
8	Cons	Constants	1.249		
9	No. of samples	231			
10	R^2	0.5284			

The following conclusions are suggested from the results.

- There is a similar negative relation between SO_2 emission intensity and SO_2 levy (the regression coefficient is 0.73 and t value is –14.692), which again implies a positive role of current levy on reducing SO_2 emission in China.
- The sectoral characteristics of SO_2 emission intensity are as follows. Due to the limitation of sample size, there are only three sectors showing significant correlation. The emission intensity of electric power industry is clearly higher than that of the other sectors (the regression coefficient is 1.504 and the t value is 2.061), suggesting further that this sector is the main source of SO_2 emission.
- In addition, the regression results show that SO_2 emission intensity in western area, particularly the southern hinterland, including Sichuan, Guizhou, Yunnan and Guangxi, is higher than that in the rest part of the nation. But this area is also where frequent acid rains cause serious damages in China, and it is the area with high sulfur coal production as well, implying potential relationships between acid rains and SO_2 emission.
- Due to data limitation, the regression results cannot reflect the relationship between enterprise ownership and SO_2 emission intensity.

2.2 Pollution Levy and Discharge Intensity

Take the year 1995 as an example, we will explain pollutant discharge intensity and pollutant discharge volume of different sectors under different EPLI. The condition of TSS pollutant discharge intensity and emission volume of respective pollutants in the major pollution sectors under various EPLI is illustrated in Figure 6. Since the discharge volume data are obtained from the calculation on township and above township enterprises, corresponding modeling results can also explain behavior of township and above township industrial enterprises (it is the same as calculations below).

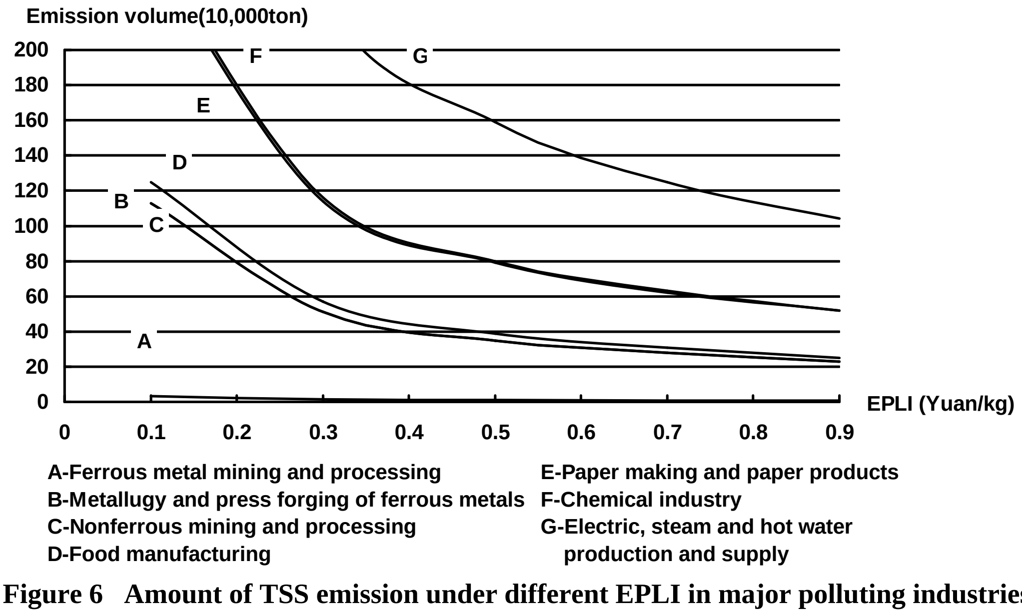


Figure 6 Amount of TSS emission under different EPLI in major polluting industries

From the sectoral characteristics of the relationship between effective TSS EPLI and discharge intensity, ferrous mining and processing industry emits the least amount of TSS, and has the minimum influence from variance of TSS EPLI. Power- steam-hot water production and supply industry emits the most. When EPLI is 0.5yuan/kg, TSS emission volume of this industry is 2.21 million tons, which is about 140 times of the former one. Look at the trend line of responsiveness, it is the paper making industry and chemical industry that are highly responsive to the variations of EPLI.

Figure 7 illustrates the impacts of effective COD levy on major pollution industries.

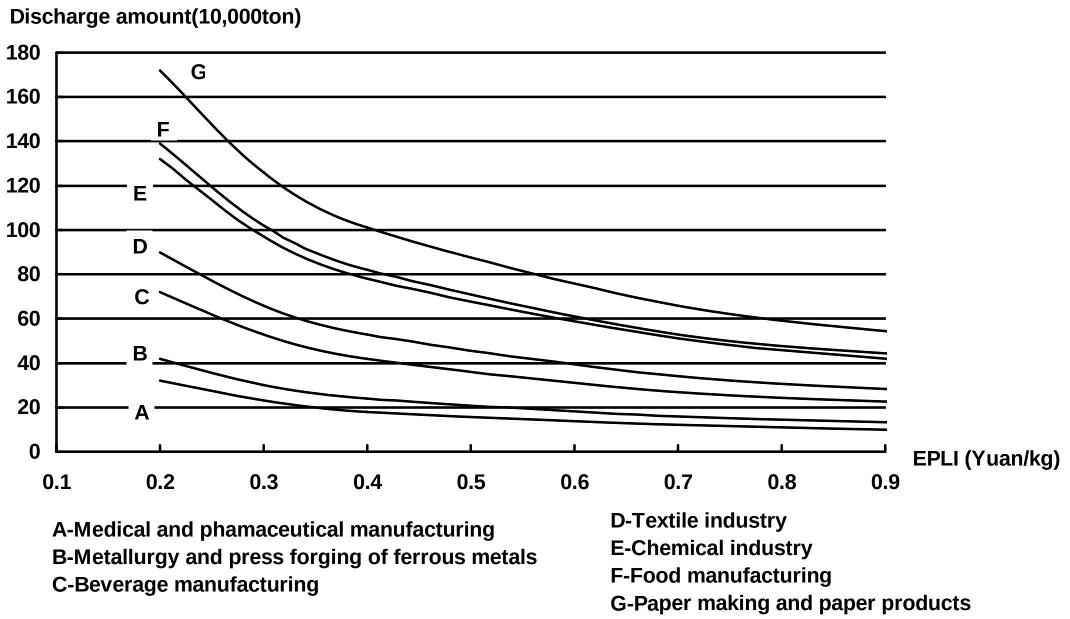
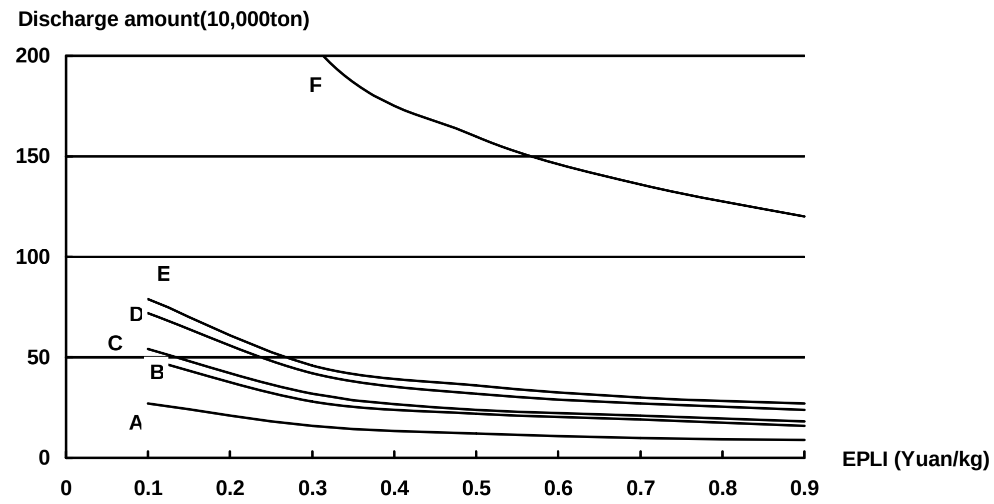


Figure 7 Impact of EPLI on COD discharge amount in major polluting industries

From the figure, it can be seen that for a given EPLI, COD emission volume is the smallest in pharmaceuticals industry, but the largest in paper making and paper product industry. This indicates that current pollution levy intensity can only have a limited stimulation on COD discharge reduction. The curve, which describes the relationship between EPLI and emission volume, shows that food manufacturing industry, chemical industry, and paper making and paper product industry are among those relatively sensitive sectors.

Figure 8 reflects the smoke emission volume of major smoke emission industries on different EPLI.

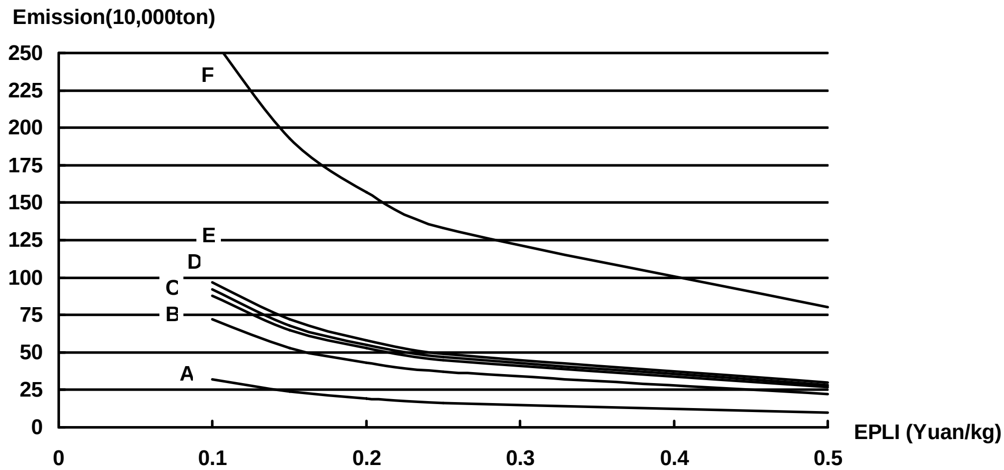


A-Paper making and paper products B-Metallurgy and press forging of ferrous metals
C-Food manufacturing
D-Construction materials and other non metal products
E-Chemical industry
F-Electic, steam and hot water production and supply

Figure 8 Impacts of EPLI on smoke and dust emission in major polluting industries

For the sectoral impacts of EPLI, under a given EPLI, emission volume of electric power industry is clearly higher than that of other sectors with a disparity of 10 times. There is no significant difference of emission volume among the other five sectors, though. It can be noticed that papermaking industry emits the least industrial dust and the ferrous metallurgy and press forging is second to it. The slopes of the curves show that the relatively sensitive sector is electric power industry, followed by chemical industry and construction material and non-metal product industry. But it should be noted that the stimulation effect on smoke reduction of electric power industry is not significant. This obviously relates to the high reduction level of smoke emission of this sector.

Figure 9 demonstrates the effects of SO_2 EPLI on the main pollution sources of SO_2 and the comparisons among them.



A-Smelting and processing of nonferrous metals
B-Construction materials and other non metal products
C-Smelting and processing of ferrious metals
D-Chemical industry
E-Food manufacturing
F-Electric, steam and hot water production and supply

Figure 9 The effects of SO_2 EPLI on SO_2 emission in the main polluting industries

Comparing the impacts of SO_2 EPLI on the main pollution sources, it is found that the mostly affected sector is electric power industry. Nonferrous metallurgy and press forging industry is the least affected one. At the levy rate of 0.2 yuan/kg, the emission volume in the former is 8 times of the size of that in the latter. It can be seen from the figure that there is little variance among the impacts of EPLI on nonferrous metallurgy and press forging industry, chemical industry and food manufacturing industry. Electric power industry and food manufacturing industry are relatively sensitive to the levy policies, and nonferrous metallurgy and press forging industry can be viewed as the least sensitive one.

3.0 Environmental Performance of Industrial Enterprises

The environmental performance of a plant is affected by many internal factors such as its sector category, ownership and scale. In the meantime, external factors such as pollution levy also have impacts on that.

3.1 The Internal Factors of Plants That Affects Environmental Performance

During the process of establishing the relevant functions of an industrial plant, the properties determine the environmental performance of the plant. The properties of an enterprise include sectoral category, scale and ownership.

The Impacts of Sectoral Category on Environmental Performance of A Plant

Due to different raw materials, production processes and pollution control technologies, the behavior of enterprises in different industries differ correspondingly. Within the same industry, depending on the characteristics of the industry, the responses to environmental policies can also differ between enterprises.

It can be seen from the aforementioned analyses that major sectors of TSS emission have distinct environmental characteristics. In the middle of 1990s, the biggest TSS emission sector was ferrous metallurgy and press forging industry. But its emission intensity was not the highest. Pollution levy impact is weak. However, with the relative low level of marginal abatement cost, the sector should be taken as the first choice for TSS reduction. As for paper making and paper product industry, which is the second largest TSS polluter in the middle of 1990s, it is sensitive to pollution control policies. Although its pure end-pipe abatement costs are relatively low, as discussed above, the cost will have a great increase if alkaline recycling process is considered, so it will need substantial investment to reduce the TSS discharge of this sector. Attention should also be paid to TSS discharge of chemical industry. This industry has high marginal abatement costs, therefore TSS reduction of this sector needs substantial investment.

By the same approach of analyzing TSS emission, the best sector for COD reduction in China, at present, is food and beverage-manufacturing industry, followed is chemical industry. As for paper making industry, due to its high reduction cost after consideration of alkaline recycling, it is not appropriate to be taken as a major reduction industry.

For water pollutant reduction in China, the best choices are ferrous metallurgy and press forging industry, food manufacturing industry, chemical industry, electric power-steam-hot water production and supply industry, and pharmaceuticals industry, etc. Through different sectors have different sensitive to pollution levy, but the pollution levy must be the effective economic instrument to pollution control, so it should be reinforced, in order to reduce water pollutant discharge effectively.

Considering the environmental properties of the major pollution sectors of industrial dust, it is found that the first choice for this pollutant reduction is electric power, steam and hot water production and supply industry. In the middle of 1990s, this sector was the number one polluter of industrial dust, its discharge intensity and responsiveness towards levy are also the number one among other major pollution sectors. Its abatement cost, on the other hand, is the lowest. Thus, this is an ideal reduction object. Construction material and non-metals product industry has the same environmental properties as electric power, steam and hot water production and supply industry. It should be another important sector to reduce industrial dust. Same as wastewater reduction, the abatement cost of industrial dust in chemical industry is higher than that of the other sectors. Thus substantial investment is required, although its emission volume was the third largest in the middle of 1990s and its discharge intensity is highly responsive to emission levy.

The same as industrial dust abatement, the best choice for SO_2 reduction is electric power, steam and hot water production and supply industry. Construction material and non-metals product industry and chemical industry have similar environmental properties. They are the major sectors for SO_2 reduction. But their abatement costs are relatively high.

For atmospheric pollutants abatement, electric power, steam and hot water production and supply industry and construction material and non-metals product industry are the main pollution abatement sectors. They are also highly responsive towards emission levy. Consequently, emission levy system in these sectors should be reinforced so as to control atmospheric pollutant discharge.

The Impacts of Plant Size on Environmental Performance

Plants of different size usually have different environmental performance in the economic competitions in a market economy. Generally speaking, due to high technology and sufficient fund, the abatement costs of per unit pollutant and the discharge intensities of large plants are lower than that of the medium-sized and small ones. The above analyses show that under the present situation in China, marginal abatement cost of water pollutants of small plants is 10 times the size of that in large plants. Marginal abatement cost of atmospheric pollutants is 5 times of the size of that in large plants. Therefore it is obvious that pollution control emphasis should be put on large and medium-sized plants.

At present, township and village enterprises are increasing fast in China. In the middle of 1990s, the number of this type of plants reached 1.22 million, which accounts for 1/5 of all enterprises in the nation. Their pollution emission volume was 30%-50% of the overall discharge in that year. However, the majority of such enterprises are small in size. It will surely waste investment and resources if abatement is done by individual plants. Instead, centralized pollution control should be the major approach for their pollution abatement.

The Impacts of Ownership on Environmental Performance

After the implementation of open door policy, structural innovation took place in the economic type and enterprise ownership in China. The general tendency of the renovation is the percentage decrease of state owned enterprises and increase of collectively owned and private owned enterprises. In the middle of 1990s, product value of non-state owned enterprises exceeded half of the general industrial product. In one way, such structural change effectively breaks the limitation of planned economy and increased the vitality and efficiency of the national economy; in another, it brings in many new characteristics to the environmental behavior of different enterprises.

The regression results show that plants of other ownership, including joint ventures and stock companies, pay more marginal abatement cost of water pollutants than state-owned and collectively owned enterprises. Marginal abatement cost of atmospheric pollutants are lower in collectively owned enterprises than that in state-owned plants while they are higher in joint ventures and stock companies than that in state-owned plants. In principle, pollutant marginal abatement costs decrease in the order of joint ventures and stock companies, state-owned enterprises and collective plants. Thus, at present, joint ventures and stock companies care more about the environment, and their investment in pollution control is relatively high. On the contrary, collectively owned township and village enterprises do not care so much about the environment and spend less in pollution abatement.

The sensibility of different ownership plants to pollution control policies and instruments, such as pollution levy, are not the same. The regression results from available samples, however, do not illustrate the differences. Generally speaking, private enterprises are more sensitive to economic and policy instruments of pollution control than state-owned ones. The share of state-owned enterprises in China is declining gradually with the deepening of economic reform. Consequently, the economic and policy instruments of pollution control will surly play greater role.

3.2 Policy Factors that Influence Environmental Performance of Industrial Enterprises

According to the availability of data, the environmental demand functions for respective pollutants are established. Pollution levy is looked upon as a policy variable into environmental demand function. The focus is on analyzing the impacts of pollution levy on environmental performance of plants.

Variations of EPLI affect abatement cost and abatement rate of plants, on one hand, and emission intensity, on the other hand.

Examine the variations of EPLI and corresponding abatement rates, a general exponential relationship is found. At low abatement rates, a relative small change of EPLI increases significantly with the abatement rates; at high abatement rates, however, even small increases of abatement rates require a big increase of EPLI.

Water and atmospheric pollutants are good examples. On the other hand, for separate plant, the increase of EPLI does not course the significant increase of pollution abatement cost.

Environmental demand function illustrates, directly, the relationship between EPLI and discharge intensities. Increases of EPLI effectively accelerate the reduction of discharge intensities. Some comparisons among the four main pollutants are made here. When TSS EPLI rises to the level of 9 times higher, its discharge intensity reduces to 1/5 of the original level. When COD EPLI rises to the level of 5 times higher, the corresponding discharge intensity is only 1/4 of the original level. When smoke and dust EPLI rise to 9 times, the corresponding discharge intensity is just 1/3 of the original level. When SO_2 EPLI rises 5 times, the corresponding intensity is 1/3 of the original level. Obviously, pollution levy can control pollutant discharge. Therefore, it is one of the effective economic instruments to reduce pollution at present in China.

4.0 Conclusions

1) This paper started from the principles of econometrics and established Chinese wastewater and waste gas abatement cost function and environmental demand function. Based on them, marginal abatement costs for major pollutants were put forward; The function of pollution levy in controlling industrial pollution in China was analyzed in depth and environmental performances of Chinese industrial enterprises was also roughly discussed in the paper.

2) The abatement cost function is the primary information for analyzing the environmental performance of plants. On the bases of cost functions, this paper gave marginal abatement costs of TSS, COD, smoke and SO_2 in main pollution sectors. Impacts of various EPLI on abatement costs were analyzed.

3) The establishment of environmental demand function provided a basis for analyzing the impacts of pollution levy on pollutant discharge intensity. This paper mainly analyzed the impacts of pollution levy on the discharge intensity of the four pollutants mentioned above.

4) Through economic models, the paper comprehensively analyzed the environmental performance of industrial enterprises. The paper mainly discussed the policy factor of pollution levy and internal factors of ownership, sectoral category and plant size on environmental performances of enterprises.

5) It should be noted that it is difficult to simulate the enterprise behavior of industrial enterprises. It is especially the case for industrial enterprises in China, which is undergoing a renovation. This in a large sense is limited to theoretical level, modeling technique and data support. The modeling work developed in this paper is only a basic step for quantitative economic analysis under currently available conditions. Some imperfections may exist and further improvement is needed. For example, when establishing the demand function, we only introduced pollution levy as the policy factor due to data limitation and many pollution reduction effects are mainly attributed to pollution levy. In other words, this magnified the function of pollution levy, which obviously has difference with actual situations. Therefore, some

analysis may inevitably have some deviation, but the characterized conclusions from the analyses will nevertheless have actual meanings and reference value.

5.0 Acknowledgement

During the process of obtaining our econometric regression results about plant environmental performance, Mr. David Wheeler, the Principle Economist, Dr. Wang Hua and Ms. Susmita Dasgupta of Policy Research Department at The World Bank, provided us with all-around guidance and assistance. We would like to express our sincere appreciation to them.

The final version of the article incorporates the comments made by experts presented at the Workshop on the Economics of Industrial Pollution in China, held in Tianjian Municipality in May, 1998. We are very indebted to these anonymous experts. Special thanks are due to Prof. Xiaoming Guo, the Deputy Director General of Department of Planning and Finance, SEPA, Gai Yi, the Director General of Department of Sciences and Technologies of SEPA, for their valuable and constructive suggestions.

The ideas appeared in the article are those of the authors and do not necessarily represent those of the State Environmental Protection Administration (SEPA) and the World Bank as well as the authors' affiliations. The remaining mistakes are born by the authors themselves.

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