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THE USE OF A TRADABLE PERMIT SYSTEM FOR THE CONTROL OF RIVER POLLUTION IN WUHAN, CHINA

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I ALLOCATION OF POLLUTION PERMITS THROUGH MARKET

I-1 From Pollution Tax to Pollution Permits

As a typical external problem, environmental pollution cannot be brought under efficient control in a lassie fair economy Early in the 1920s, Pigou (1924) suggested a levy on pollution to remove the difference between private and social costs, or external cost associated with environmental pollution In theory, such a levy is capable of producing an optimum level of pollution, but in practice it has been hardly implemented due to the lack of information on external costs and constant erosion of its effectiveness by inflation and expansion of the economy. A command and control approach is able to protect the environment from excessive pollution, but it intervenes in the operation of the market and causes of inefficiency in environmental management. Late in the 1960s, the concept of pollution permits was proposed, which were defined in accordance with environmental standard and tradable in the market (Dales, 1968). In the early 1970s, the cost-effective nature of a pollution permit system was discussed and demonstrated using an equilibrium analysis (see, Baumol and Oates, 1988) However, this approach as a policy alternative was employed as late as in the 1980s when it was adopted by the USEPA for the control of waste water discharge and emission of air pollutants In 1988, a pollution permit registration system was put into operation in China but the trade of permits has hardly been institutionalized ever since.

I-2 Pollution Permits and Trading Mechanisms

Before their trading in the market, pollution permits must be clearly defined. There exists an assimilation capacity of pollutants in nature within an ecological system or an area In order to protect human health and the ecological functions, certain threshold level of pollution must be observed Based on such capacity and threshold levels, the environmental protection agency is able to calculate the total amount of pollution in a specific region and issues the number of pollution permits (D). Suppose in the region, there are N firms emitting pollutants in their economic activities Without control, every firm is allowed free emission (f_i) It is very likely that

$$\sum_{i=1}^{N} f_i > D \tag{1}$$

Due to the quantity control through permits, firms would be required to reduce their emissions to meet requirement

$$\sum_{i=1}^{N} (f_i - r_i) \leq D \quad \text{with } 0 \leq r_i \leq f_i \tag{2}$$

while r_i is the reduction by firm I. Corresponding to its technology and investment, each firm should have its specific cost function of pollution control ($C_i(r_i)$). In view of cost-effectiveness, the aim here is to minimize total control cost:

$$\min \sum_{i=1}^{N} C_i(r_i) \qquad (3)$$

Here the control variable is r_i and equation (2) constitutes the constraint. The symbols and their meanings are given in Appendix A.

Equations (3) and (2) constitute a general system of optimal control. If all the cost functions are concave, we are able to derive the first order conditions for cost-effectiveness:

$$\partial C(r_i)/\partial r_i = \lambda\,; \quad \sum_{i=1}^{N} (f_i - r_i) = D \qquad (4)$$

while λ is a Lagranrian multiplier or the shadow price of pollution control, with λ and r_i non-negative. Equation (4) indicates that the marginal cost of pollution control for each firm is equal to the shadow price of pollution, or the amount of cost-saving at the margin with given pollution permits. Each firm is assumed to be given certain amount of pollution permits in the initial allocation either though the market or through administrative procedures such that the sum is equal to D, ie

$$\sum_{i=1}^{N} q_i = D \qquad (5)$$

With the given initial allocation scheme, each firm is allowed to trade their share of permits in the market. In a competitive market, the price of pollution permit is P and the firm determines whether it should sell or buy permits

$$\min \sum_{i=1}^{N} \{C(r_i) + P \cdot (f_i - r_i - q_i)\} \qquad (6)$$

That is, the firm will make its decision on the amount of reduction, emission and sale or purchase according to its cost function of control, the number of permits as given in the initial allocation and permit price. If $f_i - r_i - q_i > 0$, firm i will buy additional permits while sell its permits if $f_i - r_i - q_i < 0$ in order that the cost of pollution control by the firm is minimized. Differentiate equation (6) with respect to r_i and let the derivative be zero, the first order condition for cost minimization is

$$\partial C(r_i)/\partial r_i = P \qquad (7)$$

This suggests that, under a marketable permit system, the optimal strategy for the polluting firm is to equate its marginal cost of pollution control to the permit price. As a result of following this strategy by each firm, the total control cost in the area is minimized

I-3 Characteristics of environmental management

From the above analysis, it is seen that a marketable permit system for pollution control combines the merits of regulation and the market On the one hand, the total amount of permits are determined on the bases of pollutant assimilation capacity and threshold levels rather than purely determined in the market although the permit setters may consider the economic implications of the number of permits This means that the quantity of pollutants is given by government regulation is followed through issuing equivalent number of permits Individual firms may discharge more or less, but the total amount of pollution is brought under strict control Environmental authority may consider regional or seasonal variations for pollution control and thus issues the amount of permits correspondingly. As such numerical permits do not increase with the economy, environmental quality will not erode with inflation and economic expansion

On the other hand, the trading of permits possesses efficiency features as the government does not have to tell how much a firm has to spend on pollution control and what amount the firm is allowed to emit The total number of permits may not be optimal for the overall economy, but the available permits as scarce resources are allocated in the market to generate either the highest output or minimize the total cost of control. This feature is not affected by initial allocation of permits as the holders and users of permits will exchange them for their own benefits

Such a marketable permit system provides a constant incentive to the firm and pollution is not free. Firms will invest in technological improvement to reduce discharge permits adjust its scale of production, or the combination of inputs such that the cost of pollution control is considered in the firms' decision making process

In the permit trading system, there is no need for the government to acquire information on control technologies and marginal control cost by individual firms as the price of permit is determined in the market, different from a tax or pollution fee which is set by the government This does not only reduce government expenditure on pollution control, but also help reduce government intervention in the market Moreover, a tax or fee is normally regarded as a burden by the firm but permits are necessary input of production and firms may be allocated certain amount of permits free of charge in the initial allocation Therefore, the firms may be more cooperative with the government in pollution control.

Despite of the merits, a marketable permit system is not a complete substitute for pollution fees or regulations First cost-effectiveness does not necessarily mean Pareto optimality for pollution control. This is because the quantity of pollution control is not derived from an equilibrium analysis but largely determined according to ecological or environmental requirements Second, the government may accept a quantity level insufficient to environmental protection when it is subject to the pressure from certain political or other groups Third, some environmental problems such as toxic substances can only be regulated and little scope is left for trading due to the requirement for environmental security

And lastly, the trading of permits involves transaction cost which is likely to hinder the implementation of a marketable permit system.

II INDUSTRIAL WASTE WATER DISCHARGE CONTROL

II-1 Quality Standard

Industrial waste water discharged to water bodies are required to meet certain standards set by the Government, which accord to the functions of surface water[1] Limits are set for quality levels and for the concentration of waste water to be discharged into respective categories of water bodies

Among the major pollutants are chemical oxygen demand (CODcr), biological oxygen demand, volatile phenol, oil, heavy metals, acidity, hardness, floating debris, etc The concentration limit for COD, for instance is set at not higher than 15 mg/l for water body designated as sources for drinking water supply, and 20, 25 mg/l for irrigation and non-body contact recreational uses Based on such concentration limits, it is possible to derive assimilation capacity and thereby the acceptable discharge rate into water bodies designated for various uses COD concentrations in waste water is much higher than the standards, ranging from 80 mg/l to 350 mg/l depending on the type of industries and the time when the factory was put into operation (Appendix B)

II-2 Discharge Fees

Incentives for pollution control were introduced as early as in 1982 when the State Council enacted a decree on levy of pollution fees, which dictates that fees be levied on air and water pollutants higher than emission limits The rate of charge increases with the concentration of pollutants, from 0 04-0.06 yuan per ton of waste water for concentration level up to 5 time higher than the limit to 0.20-0 30 yuan per ton of waste water for concentration level 50 times more than the limit The levy was increased in 1991 to 0 18 yuan per ton of waste water which is then multiplied by the number of times in excess of the standard Three years later, all the below-limit waste water is subject to discharge fee of 0 05 yuan per ton if there is any increase in concentration, pollutants or quantities

II-3 Pollution Discharge Permit Registration System in China

Water quality in large cities became deteriorating in 1970s a couple of cities in the mid 1980s introduced the approach of quantity and permit system to water pollution control The first case was recorded in Shanghai where the source for drinking water, River Huangpu, was seriously polluted by industrial and domestic waste water In 1985, Shanghai Municipal Government enacted a decree which requires that all the factories reduce their waste water discharge by 60% on the basis of 1982 level The remaining 40% of 1982 discharge total was then given as permits to individual factories. Quantity control through permit allocation and registration instead of concentration control was regarded a success in reducing river pollution. However, the trading of permits hardly occurred as the reduction was specified for individual factories through administrative power and government subsidy was availed. As a result, no market was established for permit trading in Shanghai

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[1] Surface Water Standards, GB 80-9211, 1980 Five categories of water uses are defined for water uses categories I-3 are mainly for natural reserves and sources for drinking water supply Category 4 is suitable for industrial and recreational uses without human body contact Category 5 can be used only for irrigation.

With the success story in Shanghai, the National Environmental Protection Agency initiated a scheme of pollution permit registration system. As required by this system, all the polluters must apply, register and then be certified to discharge If the total amount of discharge is within certain quantity level, it will be issued a permit to discharge up to the quantity level by local environmental protection agency If on the other hand, the current discharge level exceeds the prescribed level, the polluter will be given a temporary permit and be urged to reduce its discharge After years of pilot experiment, the system was introduced nation-wide in 1994 and in one year, 480 cities established registration system and 77,272 factories were registered About half of the cities issued pollution permits to 12,247 factories, with a total of 13,447 permits.

China's environmental policy has been shifted from concentration control to quantity control in the early 1990s At the very end of 1995, the State Council approved the policy to adopt quantity control of pollution and requires that total emissions/discharge in 2000 be set at 1995 level[2] This is rather ambitious as the planned annual GDP growth rate is 10% in contrast to zero increase in emission/discharge. Under this requirement, total discharge should not be increased disregarding the concentration levels

III STUDY AREA

III-1 The Economy and Waste Water Discharge in Wuhan

As the largest industrial base with an area of 8,467 square km in central China, Wuhan is located right in the middle of the Yangtse River and Beijing-Guangzhou railway Total population amounted to 7 million in 1995. In 1994, GDP totaled 44.9 billion RMB Yuan Total industrial output reached 72 8 billion RMB Yuan, 2/3 of which being from heavy industrial sectors Major industrial sectors include primary metallurgy, chemicals, textile, paper making and food manufacturing

Yangtse River flows through the city and divides the city into three parts together with River Han, the largest tributary of the Yangtse (see fig 1). Water for industrial supply is largely from the River and waste water goes back to the river As the amount of water passing through the city is substantial in quantity, there is no limit to control extraction from the river and so was the discharge of waste water prior to the 1980s Therefore, river water has been treated as a free goods and managed as a common property, or every body's property

Waste water discharge in Wuhan has been increasing[3] In 1994, total waste water discharge was 1,224 million tons, in comparison with 1,074 in 1986 and 816 in 1981 Discharge by industries increased from 704 billion ton in 1993 to 734 in 1994 Because of waste water treatment and increased rate of recycling, the rate of increase of pollutants is higher than the amount of waste

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[2] Song Jian, Speech by State Councilor at the National Conference of Provincial Environmental Administrators. People's Daily, December 20, 1995, p. 5.

[3] The History of Environmental Protection in Hubei, pp 30-32, Wuhan Environmental Data, 1995

water the amount of COD for instance was 132,600 tons in 1994, 32.7% higher than the figure in 1986, which is 17 3 percentage points higher than the rate of increase in waste water discharge for the same period.

The assimilation capacity of pollutants from the city is rather large owing to substantial quantity of water and speed of river flows As a result, the overall quality of water is regarded fine, suitable for drinking water supply However, this statement is somewhat superficial as the quality figure is based on cross-sectional average at the upper and lower ends of the city section According to monitoring specialists, the samples are far from the end of sewage pipe and pollution belt along both banks of the river is unable to be represented by the average figures But the extraction point of the river is near the river bank where pollution is most serious Also, as pollutants accumulates in river water, pollution is further transferred to down stream.

Table 1 Levies on Pollution Discharges in Wuhan, 1994

	1993		1994	
	collected(10^4Yuan)	% of total	collected(10^4Yuan)	% of total
no of payees	1368	/	1928	/
fees on				
above-limit discharge	**3001.3**	**89.28**	**3881.0**	**83.70**
water pollutants	2301 8	68 47	3063 1	66 06
air pollutants	498 0	14 81	508 3	10.96
solid waste	3 5	0 10	21 4	0 46
noise	198.0	5 89	288 2	6 22
radio actives	/	/	/	/
waste water	**109.4**	**3.25**	**425.0**	**9.17**
others*	**251.0**	**7.47**	**331.0**	**7.14**
total	***3361.7***	***100.00***	***4637.0***	***100.0***

Sources: Wuhan Environmental Protection Bureau, Statistical Data Report, 1995.

* items including fines, increase in unit fees on certain pollutants and compensatory payment

III-2 Waste Water Management in Wuhan

Based on national and provincial regulations and decrees, the city government has authorized the city environmental protection Bureau to impose on and collect discharge fees from polluters Although such fees were in place in 1980, they did not seem to be an effective way to control pollution There are two reasons for this (1) the rate of levy was considered too low as not to deter polluters and (2) wavers and ignorance of the levy enabled many polluters to escape from paying In recent years, the collection of pollution fees has been intensified In 1994, total collection amounted 46.37 billion RMB yuan from 1928 enterprises, 37 94% higher than the previous year 92 9% of the fees were from waste water discharged into water bodies (table 1) Although water pollution has caused serious concerns, no study has been carried out on natural assimilation capacity and on the allowable amount for waste water discharge.

III-3 Industrial Waste Water Discharge

According to industrial monitoring data on polluters, the biggest ones are from chemical, paper making, primary metallurgy, coking and gas and petroleum sectors The amount of industrial waste water discharged from 300 biggest producers accounts for 37 3% of the total from 3000 biggest ones and 22 3% of national total. The percentage share of pollutants by the 300 biggest among the total are even higher, being 67 1% and 43% respectively Major water pollutants include volatile phenol, NH_4-N, COD, etc[4]. Statistics shows that industrial waste water discharged in Wuhan takes an unproportionately high share of national and provincial totals. Among 51 key cities in China, Wuhan accounts for only 1.7% of the number of enterprises on the national monitoring list but 7.36% total waste water discharged and 7 91% of the total COD. Within Hubei Province, the number of enterprises is less than 10% of the provincial total, as compared to more than 40% share of total industrial waste water, half of COD total (table 2)

Table 2 Waste Water Discharge Wuhan compared with other cities (1994)

	no of dis-chargers	total discharge (10^4t)	industrial waste water (10^4t)	volatile phenol (t)	COD (t)	Cr^{+6} (t)	oil (t)
51 cities	27843	796040	515644	1339 41	1676677 7	113 21	28108 2
Shanghai	2631	118126	83683	80 26	1636610	9 66	6140 0
Nanjing	635	66925	51942	278 89	53643 6	12 31	1958.03
Wuhan	498	58562	43624	97 42	132574 3	5.70	1740.0
Chongqing	1031	30574	17903	37 21	35450 5	6 68	1299 8
Hubei Prov	2611	142685	83943	341.06	282686 8	28 06	3876 6
Wuhan/51 cities(%)	1 97	7 36	8 46	7.27	7 91	5 04	6.19
Wuhan/ hubei (%)	19 07	41 04	51.97	28.56	46 90	20.36	44 88

Source : China Environmental Yearbook 1995, pp 427-31, 448-50 。

4 China Environmental Statistical Yearbook 1995, pp. 164-6

The large and medium state owned enterprises constitute the major producers of waste water in Wuhan. 57 state and provincial owned enterprises in Wuhan consumes 85% of total fresh water for industrial uses and 77% of total waste water discharged (table 3) However, they are also the leaders of waste water treatment in the city Over 80% of the investment and operation expenditures in the city were spent by these enterprises. Majority of enterprises discharge their waste water into Yangtse river directly, with a total amount of 375 3 million tons in 1994 The most polluting sectors follow the similar pattern to the national, including chemicals, paper making, metallurgy, food manufacturing, textile and dying, and medical.

The above discussion reveals that (1) Wuhan takes a high proportion of the amount of industrial waste water in comparison with the national, provincial and other cities along the main stream of the Yangtse; (2) volatile phenol and COD are the major water pollutants in Wuhan an (3) large and medium enterprises are the biggest contributors to both water pollution and industrial output Based on these features, this analysis will concentrate on a limited number of key polluters The selection of enterprise considers (1) COD, the key pollutant to be used for permit trading, is 200 tons per annum or higher; (2) waste water is discharged into the Yangtse directly or to water bodies which are connected with the river In total, 16 heaviest COD polluters are selected for an exercise of permit trading and the details of these enterprises are given in table 4. These enterprises are from industrial sectors such as chemicals, paper making, food manufacturing, primary metallurgy and textiles The share of total waste water from these 16 enterprises accounts for 87.59 % of the 57 total and COD, 95% It may be noted that the COD concentration in waste water discharged from Wuhan Iron and Steel Corporation meets the state set discharge limit but it still selected because it is the biggest COD contributor and its control cost in terms of unit COD reduction can be of illustrative significance

Table 3 57 key polluters as compared with industrial total in Wuhan, 1994

	57 average	57 total	% of city total
industrial output(10^8yuan)	2 32	132 43	43%
invest. in treatment(10^4 yuan)	406 72	23182 9	81 8%
operational cost 1994 (10^4 yuan)	74 62	4253 3	86 6%
pollution fees paid (10^4 yuan)	46 27	2637 1	56 9%
waste water discharge (10^4t)	792 68	45182.9	77 0%
waste water treated (10^4t)	684 67	39026 0	85.0%

III-4 Total Quantity

The determination of total quantity as the basis for permit trading should be based on scientific assessment of natural assimilation capacity of river water This would involve complex modeling of chemical and hydrological processes Due to variations in concentrations in waste water, the quantity should not be given in terms of waste water discharged. This means that the amount of pollutant rather than waste water should be used as the quantity index Second, only one or two key or comprehensive indicators should be selected as the key pollutant for quantity control In this analysis, COD is selected for two reasons First, it is the most important pollutant that causes river pollution in Wuhan and it is an overall indicator rather than a single chemical element such as heavy metals or drifting debris It has been regarded as the most indicative index of water pollution in China For instance, the most heavily polluted Hui River in Northern China, COD is said to be the causes In order to meet the target of purifying Hui River, the government has set the target to reduce 95% of the current COD quantity discharged into the river The total reduction was calculated to be 1 01 million ton per annum Although the natural assimilation capacity of Yangtse is much larger than Hui River, the amount of COD produced in Wuahn reached 132,600 ton per annum, a not negligible figure Therefore, for simplicity, COD will be used to define quantity control and cost-effective analysis for permit trading

It seems that there is a need for quantity control, but little work has been done on derivation of quantity. Using the national target of fixing the discharge level for 2000 at 1995 level, the amount of COD discharges from industrial sources in Wuhan must be reduced with respect to either discharge per unit output or total quantity by each enterprises as the economy in the city is to grow at 12% annually for the period of 1995 to 2000. To meet GDP growth, industrial waste water will increase though much lower than GDP rate Taking into account of technological improvement and clean production innovation and the actual rate of increase in the early 1990s, waste water increases at 4% annually. In order that the total COD discharge does not exceed the 1995 level, a 15% of 1994 COD discharge total should be reduced

IV METHODOLOGY

IV-1 Treatment Cost Function

Once the pollutant and quantity figures are determined, we need to specify the cost functions for COD reduction Such functions should vary with different types of waste water In earlier discussion, a general form of treatment cost function was used but this form must be further specified for meaningful empirical analysis In general, the cost function include two parts investment cost and operation cost. Investment is needed in land, buildings and equipment while operational expenditures are required to cover variable costs such as labor, chemicals, energy, electricity All these costs relate to the scale of treatment facilities and such relationship describes the functional form of cost, scale of treatment, and the reduction of pollutants.

Investment Cost Function

Investment cost C_{inv} cost is the function of Q, the quantity of waste water to be treated per unit of time (day) and D, the amount or proportion of pollutants to be removed from waste water That is

$$C_{inv} = f(Q,D) \tag{8}$$

In most cases, C_{inv} is a concave function, increasing with Q and D but marginal rate of change is not linear. This suggests that at certain scale of treatment and reduction rate, marginal cost of investment is minimal Under such circumstances, the enterprise may choose specific technology and suitable scale of treatment investment to minimize its control cost If the investment cost is too high, the polluter may ask some other enterprises or some of them invest jointly instead of building its own treatment facilities. Such differences in treatment scale and discharge quantity constitute the incentives for permit trading.

Operational Cost Function

Operation expenditure holds a linear relationship with investment cost, that is, the larger the scale of treatment facilities, the more operational cost (C_{op})

$$C_{op} = K\ C_{inv} \tag{9}$$

where K is a constant Due the variation in treatment technologies and processes, the values of K may differ and thereby operational cost will change accordingly As a result, the variation among enterprises and different sectors will affect the decision making for pollution control

Since the early 1980s, China's Environmental Protection Agency has sponsored a series of studies on treatment cost functions Such studies cover most of the polluting sectors and functional forms were derived for different regions, types of treatment technologies and industrial sectors. According to the results, investment cost for waste water treatment normally takes an exponential form

$$C_{inv} = \alpha\ Q^{\beta}$$

where α and β are parameters obtained statistically Accordingly the operation cost function is

$$C_{op} = k'\ Q^{\beta'}$$

where $k'=K\alpha$ All the functional forms and their parameters are given in Appendix C.

In this case study, no attempt is made to derive investment and operation functions for individual enterprises due to the lack of empirical data for meaningful statistical analysis As many enterprises have not invested in treatment facilities and some existing facilities were not in operation, the cost data from some enterprises are not employed in the analysis directly Rather, the functional forms as listed in Appendix C are adopted. As some of the parameters were derived using data from different are and industrial sectors, only those which are directly related to and suitable for waste water treatment in Wuhan are singled out for use To determine which function is suitable for a specific enterprise, we have to match COD concentration, the quantity of waste water discharged and the reduction rate required in the case area with the functions in Appendix C

IV-2 Total Control Cost

In order to reduce COD discharge, enterprises have to treat their waste water before releasing. The problem here is the cost of treatment Such treatment does not only require investment and operation expenditures as described earlier, it is also likely that some discharge fees may be reduced as discharge standards are met at the end of the pipe and the amount of waste water is decreased due to increased recycling Therefore, for an enterprise, it has to invest in treatment facilities and pays for operation, but it may receive some saving from lower payment of levies on above-limit-discharge (Y) and waste water fees (Z) Therefore, the actual cost (C_{act}) for waste water treatment takes the following form

$$C_{act} = C_{inv} + \omega\,(C_{op} - Y - Z) \tag{8}$$

where ω is a net present value factor. As capital expenditure is a sunk investment where other elements occur every year, these elements must be transformed into present value for total cost aggregation Using the survey data from Wang et al (1992), the operational life of the facilities is set at 20 years and discount rate uses a figure of 8%. The present value factor is thus calculated at 9 818

Investment and Operation Cost

Using the functional forms in Appendix C, we have the following equations for cost estimation

$$C_i(_{inv}) = \alpha\, Q_i^{\beta} \tag{9}$$

where i represents for enterprise i Q uses the daily treatment capacity figure in terms of tons. The operational cost function is

$$C_i(_{op}) = t(\alpha\, Q_i^{\beta'})Q_i \tag{10}$$

where t is days in operation in a year $\alpha\, Q_i^{\beta'}$ is unit operational cost. $C_i(_{op})$ is then the total annual operational cost for enterprise i.

Levies on above-limit-discharge

Y is product of unit levy (e, yuan/ton) and total quantity (Q) of above-limit-discharge. Since the number of folds in exceeding the discharge limit is based on the concentration of pollutants in waste water, the annual payment for above-the-standard discharge is calculated as follows

$$Y_i = teQ_i\,\frac{U_i^1 - U_i^2}{\overline{U}} \tag{13}$$

where $\overline{U}$ is the discharge standard, which is 100mg/l for waste water into Yangtse River, e is o.18 per ton while U_i and U_j are COD concentrations before and after treatment

Discharge Fees

This fee is levied on the quantity of waste water discharged As some of the waste water is reused, the reduction of waste water discharge should be the product of daily treatment and the recycling rate δ Therefore the saving by the enterprise due to treatment is

$$Z = tQ_i e' \delta \tag{11}$$

where e' is discharge fee, currently at 0.05 yuan per ton and δ the recycling rate.

With above specification, the total expenditure on COD treatment should be

$$C_i = \alpha Q_i^{\beta} + t\omega\left[\alpha' Q_i^{\beta'} - eQ_i \frac{\left(U_i^1 - U_i^2\right)}{\bar{U}} - e'\alpha Q_i\right] \tag{15}$$

IV-3 Total cost

C_i is for enterprise i only, and we need to aggregate expenditure of individual enterprises to obtain the total cost As identified earlier, 16 biggest COD dischargers were included in permit trading and costeffectiveness analysis. Two alternatives are experimented here. uniform compliance and permit trading

Uniform compliance

Under this scheme, a uniform rate of COD reduction of 15% is to be applied to all the enterprises disregarding their differences in discharge quantities and treatment cost. Therefore, the total cost of control should be the sum of costs as spent by individual enterprises·

$$\sum_{i=1}^{16} C_i = \sum_{i=1}^{16} [\alpha Q_i^{\beta} + t\omega\left[\alpha' Q_i^{\beta'} - eQ_i \frac{\left(U_i^1 - U_i^2\right)}{\bar{U}} - e'\delta Q_i\right]] \tag{16}$$

As 15% $\sum_{i=1}^{16} Q_i = 15\% Q_{total}$, the goal of total quantity control is realised.

Cost Effectiveness Compliance

With this scheme, individual enterprises are required to reduce their discharge by 15% provided that the total discharge is reduced by 15% This means that those enterprises with low treatment cost may treat more while the high treatment cost enterprises may reduce COD discharge less or zero. Thus the objective function is

$$\min\ C = \sum_{i=1}^{16}(C_i)$$

with a constraint given as

$$\sum_{i=1}^{16} r_i = D \geq \overline{D} \tag{17}$$

where $\overline{D}$ is total reduction of COD as required and D the total removal by all the enterprises. The solution of the objective function will ensure a least cost compliance with quantity control In order to have r_i related to Q_i, we need to consider COD concentrations and the rate of COD removal after treatment (ε)

If the daily treatment capacity is Q_i, COD concentration in waste water is U_i, the annual removal of COD by enterprise i should be derived by

$$r_i = t\varepsilon_i Q_i \bullet U_i$$

So the constraint function can be rewritten as

$$\sum_{i=1}^{16} t\varepsilon_i Q_i \bullet U_i \geq \overline{D} \tag{18}$$

Because the total treatment of waste water by enterprise i cannot be negative and cannot exceed the amount of total discharge, the range of treatment should be within 0 and Q_{total}. Thus we have an optimal control system for minimizing total treatment cost subject to the requirement of 15% COD reduction and the feasible range of treatment capacity by enterprise i

$$\min \ C = \sum_{i=1}^{16}(C_i)$$

$$= \sum_{i=1}^{16} C_i = \sum_{i=1}^{16} [\alpha Q_i^{\beta} + t\omega\left[\alpha' Q_i^{\beta'} - eQ_i \frac{(U_i^1 - U_i^2)}{\bar{U}} - e'\delta Q_i\right]]$$

s t

$$\sum_{i=1}^{16} t\varepsilon_i Q_i \bullet U_i \geq \overline{D}$$

$$0 \leq Q_i \leq \overline{Q_i} \tag{19}$$

As the functional form of control cost is non-linear, one way is to transform the nonlinear equation into a linear one (Wang et al, 1992). Such transformation can be a tedious task and the results depend upon the sections in the transformation. As some software such as GAMS is available for dealing with nonlinear problems, nonlinear equations are not transformed into linear ones

V RESULTS

V-1 Uniform Compliance

Based on the total quantity control objective, each enterprise is prescribed a quota for COD reduction As the quota is given in COD instead of waste water, the actual reeducation of waste water may not be the same as 15%. The reduction of waste water discharge is given as

$$\Delta Q_i = r\% \ Q_i(1/\varepsilon_i) \qquad \varepsilon_i \leq 1 \tag{20}$$

where the daily reduction of waste water discharge compatible with 15% COD removal, r% is COD removal rate, being 15% as required; e_i is the rate of COD removal under the treatment process, ranging from 0 4-1.0 The COD reduction, waste water reduction under uniform compliance re given in table 5

The total cost of compliance amounts to 90 71 million RMB yuan. Unit reduction cost varied considerably among enterprises, ranging from less than 800 yuan per ton COD to over 70 000 yuan per ton Average cost is 15 807 yuan per ton COD concentrations in waste water from some enterprises are already lower than the limit and further reduction can be expensive For instance, the unit removal cost of COD from Wuhan Iron and Steel Corporation exceeds 20 000 yuan per ton, in contract to lower value of 800 yuan per ton by Wuhan Gourmet Powder due to its effective removal of high concentration COD and saving of waste water fees and levies This simple comparison of cost variation suggests that the removal of an additional ton of COD by low cost enterprises would lead to a saving of tens of thousand yuan at the margin. This saving cannot be realized due to strict regulation of uniform compliance

V-2 Costeffectiveness Compliance

In contrast to uniform compliance, which gives a uniform level of reduction across all the enterprises and no incentives for the low cost polluters to reduce more, cost-effective compliance does not specify the amount of COD reduction for individual enterprises if the total quantity is met. This flexibility leads to a cost saving for COD reduction cost as a result of exchange of reduction quotas among enterprises The amount of total saving would be

$$\Delta C = C_{uniform} - C_{trading}$$

The results from calculation show that, enterprises with high treatment cost would not reduce their share of COD reduction quota as the compliance is not uniform This lowered the compliance cost considerably Total compliance cost is now only 23 17 million RMB yuan, 3/4 less than uniform compliance The sources of such cost-effectiveness are from the transfer of high cost treatment to low cost treatment and the economy of scale in treatment The scale of economy is an important factor as the functional form of treatment investment is exponential. However, the expansion of treatment capacity is not infinite Higher treatment capacity can help reduce the unit cost of COD removal. In terms of COD reduction, 15% of the total COD discharge is removed from the waste water although the amount of waste water treated is only 5.7% of the quantity under uniform compliance

V-3 Trading of Discharge Permit

The above cost saving is phenomenal which could be achievable under a permit trading system. Under uniform compliance, the average unit reduction cost per ton of COD is 15 807 yuan This might be the initial price for trading say P If the unit cost of COD reduction by enterprise i is higher than P, the enterprise would be willing to buy permits in the market and the difference would be the saving for that enterprise. At the same time, the permit seller would also benefit from the trading as the permit price P is higher than its unit cost of removal of COD However this price would not hold though as more permits would be availed in the market and unit COD removal cost would be further reduced. As a result, the price of permit would be lowered until an equilibrium price is reached Under the cost-effective framework, the minimum cost solution results in an average cost of 4038 yuan per ton COD But the price of permit is unlikely to be so low due to the existence of transaction cost, i.e. the cost of information on permit trading Enterprises with cost lower than the average cost under uniform compliance may be reluctant to buy or sell their permits since they may believe that their scale of treatment capacity may be enlarged in the future Therefore, the average cost under effectiveness compliance is not employed as the permit price For reasons of simplicity, we simply use the mean value of the average costs under uniform compliance and effectiveness compliance as the market price to demonstrate the benefits to both parties of permit trading and society Under this treatment, the permit price is set at 10000 yuan per ton of COD removal

The results are summarized in table 6 In total, there are 11 enterprises that bought permits from the market where 5 took advantages of their low removal cost and received net gains from selling their permits. Both parties are net gainers, with the smallest figure of 335100 yuan and the largest saving of 29 77 million Total cost saving amounts to 67 53 million, with an average cost saving for each enterprise being 4 22 million.

V-4 Discussion of Results

The above results are consistent with hypothesis that the trading of pollution permits is more cost-effective than uniform compliance with the same achievement of quantity control The figure as obtained in this analysis is from 16 enterprises only and the potential of such benefit can be promising.

If we compare the above results with actual survey data, it may be noted that they share an overall pattern of in terms of investment and sector structures The survey data show that there is a tendency of scale of economy in treatment investment Treatment facility sets with investment of over 100 000 yuan accounted for 40 9% of total in number but 95% of total investment This trend of economy of scale is further demonstrated in this analysis Polluters concentrate on a few industrial sectors and they also invest heavily on pollution abatement Paper making and chemicals are large dischargers, but they can also be effective removals of pollutants Therefore, the concentration of pollution control investment on a few sectors in a reasonably large scale is supported by empirical survey data.

Operation cost is not a small amount The present value of such cost can be higher than capital investment in treatment facilities This cost structure reflects the difficulties in keeping the treatment facilities running Because of high running cost, many facilities are left there unused Enterprises simply pay the discharge fees and levies and let their treatment facilities lying there. This suggests that the trading of permits can promote the full use of existing treatment capacities.

VI POLICY IMPLICATIONS

It has been established that the trading of permits can be a cost-effective approach to environmental as a common property management. To apply such a system of permit trading, there is a need to further and improve existing environmental policies

VI-1 Institutionalizing permit registration system and establishing a permit trading framework

China is now on its way to a market economy through a period of transition. The once effective command and control approach prevailing under planning system is retreating from its role of dominance and elements of free market are now prevailing. Permit registration system provided a sound basis for determination of permits and the trading of such permits Therefore, it appears that there is only one step towards the establishment of a pollution trading system. That is, there exists not only a scope for permit trading for pollution control as an environmental policy alternative, but also some sound basis and conditions for the operationalising such a system

However, there are a number of issues to be clarified for a smooth transition to and implementation of permit registration and trading system First, the quantity of permits need be carefully assessed Environmental authority is in a position to modify or change the number of permits conveniently with rather immediate effect of environmental quality guarantee, but enterprises will take time to respond to the expansion or contraction of permit numbers This can cause the fluctuation of permit price and affect the long term decision making by individual enterprises Therefore, the environmental authority should consider the economic implications for enterprises in registering, certifying and altering the number of discharge permits

Second, discharge permits may be regarded as an input in production process by enterprises, or a limited right to pollute. Their initial distribution may involve equity concerns, but the trading can be seen a pure efficiency issue It is up to the permit holders to decide how to use the permits Environmental protection groups or community may buy the permits for not polluting simply for a better environmental quality Therefore, it is necessary to establish certain institutional framework such that discharge permits are treated as a tradable goods The government may normalize the trading procedure, but should not intervene in the trading process

Third, attention should be paid to transaction cost The cost of acquiring necessary information can be high and erode the potential benefits from permit trading The government may provide such information as part of the institutional framework, but it will mean that the government is to bear the cost Alternative, permit brokerage may develop for such services. Permit brokers may work on a regional or national basis However, they should not be regarded as government affiliates and should be allowed to undertake their business independently

VI-2 Transitional Policies

It will take some time to have a permit trading system operational In the city of Wuhan, a majority of state owned enterprises are heavy polluters and in a disadvantaged position in the trading market as their equipment are out-dated and pollution prevention facilities are not installed Apart from pollution problems, these enterprises are experiencing hardships their products are less competitive with respect to style and quality If they are forced to buy discharge permits, an additional burden may lead to bankruptcy, which is politically unacceptable as the unemployed must be of serious social concerns. To avoid such social costs, permits may be granted free initially to these enterprises Such permits will either help them to ensure the viability of their production or be made to exchange other resources to update technology and install recent pollution reduction equipment This policy by nature is a subsidy, but such grant is of greater benefits to the transition to a permit system than a package of money subsidy The enterprises may manage the permits as a asset in the market while the government does not know the actual need of individual enterprises. However, the goals of a permit trading system are not affected· strict compliance with quantity control and efficient allocation of discharge permits

Another type of subsidy during the transitional period is the need for the government to plan and invest in waste water collection system In order to achieve the economy of treatment scale, waste water from two or more enterprises may be treated together But such potential of cost saving may not be achievable due to the lack of collection system, which can be very expensive for individual enterprises. In these circumstances, the government may step in for support Such support will certainly speed up the implementation of a permit trading system.

VI-3 Combination of Various Policy Alternatives for Effective and Efficient Environmental Management

A system of marketable discharge permits has its advantages in environmental management, but it does not necessarily a panacea for all environmental problems Strict regulations are necessary for toxic and radioactive pollutants, while fees may be levied to internalize environmental costs for some other pollutants such as the emission of green house gasses As there is a variety of pollutants in industrial waste water, it may be impossible to prescribe permits for individual pollutants. In order to select the right policy alternative for the control of specific pollutants, there is a need to identify the key pollutants and assess their environmental impact

VI-4 Further Areas of Study

In this analysis, river water is considered a common property and the discharge of pollutants into river water is viewed as the use of scarce natural assimilation capacity. Quantity control of discharge may secure the resource base and market allocation of the limited quantity in the form of permits is seen to have the potential for efficient use of the common property The results show that permit trading in terms of COD discharge quotas possess the characteristics of cost-effectiveness of limit compliance. However, in interpreting the results and applying the system of permit trading, caution should be taken.

First, only COD is taken as the pollutant in waste water In many cases, COD may not represent the key pollutants. Perhaps there is a necessity to build a comprehensive model to include most of the key pollutants in waste water such that an overall index is developed and used as the permit to reflect overall pollutant concentration in waste water With such a model, the enterprise will respond to reduce all the key pollutants since the permits are calculated on a set of pollutants in its discharge waste water

Second, the dilution of pollutants in river water was not considered in the model. Such treatment simplified the analysis but seasonal changes of river water and speed of flows can be of significance to quantity control For instance, in water when river flow is low, the assimilation capacity will also be low The enterprises may change their production schedule or store their waste water until the flood season when assimilation capacity is at its maximum Therefore, the incorporation of hydrology and dilution processes into the model would improve quantity control and thereby efficient achievement of limit compliance

Third, in this analysis, a simple assumption was made that all the enterprises were given the permits in proportion to their existing discharge without considering the implication of equity issues However, initial distribution of permits conveys equity implications and alternatives of such distribution must be assessed and compared for a politically acceptable scheme This may represent another area for further examination.

Fourth, domestic sewage has been on rapid increase in recent years along with pollution growth and improvement of living standard. As such sewage has caused serious eutrophication problems and no charge has been levied, the economic costs involved in water pollution and control need be evaluated The permits for domestic discharge may be measured by household consumption figures, their trading is different· domestic sewage must be collected and treated together One cannot imagine one household building a treatment plant. But Some households in areas where there is no treatment facility to buy permits from places where treatment plants are in operation. As the domestic sewage constitutes one of the most difficult pollution problem to be tackled, economic incentives must be introduced to bring such discharge under control

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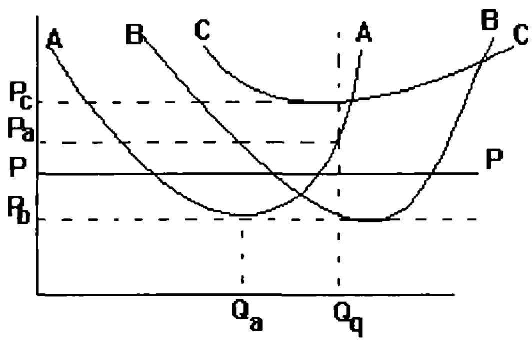
APPENDIX A SYMBOLS AS USED IN THIS ANALYSIS

symbol	meaning	unit
Q_i	decision variable , the amount of industrial waste water treated by firm i	tons/day
$^{1}_{i}$	COD concentration before treatment by firm i	mg/l
$^{2}_{i}$	COD concentration after treatment by firm i	mg/l
$\varepsilon_i^{'}$	% reduction of COD by firm i	%
$\overline{D}$	total amount of COD to be reduced	tons/day
$\bar{}$	COD concentration limit in ind waste water	mg/l
δ_i	recycling rate of treated waste water	%
Q_{total}	total daily industrial waste water discharge	tons/day
$\overline{Q_i}$	daily waste water discharge by enterprise i	tons/day
λ	Lagarannan multiplier	
D	total industrial waste water discharge	tons
fi	total industrial waste water discharge by enterprise i	tons
p	unit price of discharge permit	Yuan/ton COD
qi	number of permits allocated to enterprise i	tons
e	rate of levy on waste water higher than limit	Yuan/ton
e'	fees on discharge of industrial waste water	Yuan/ton

APPENDIX B COD(MG/L) DISCHARGE STANDARDS FOR INDUSTRIAL WASTE WATER BY SECTORS

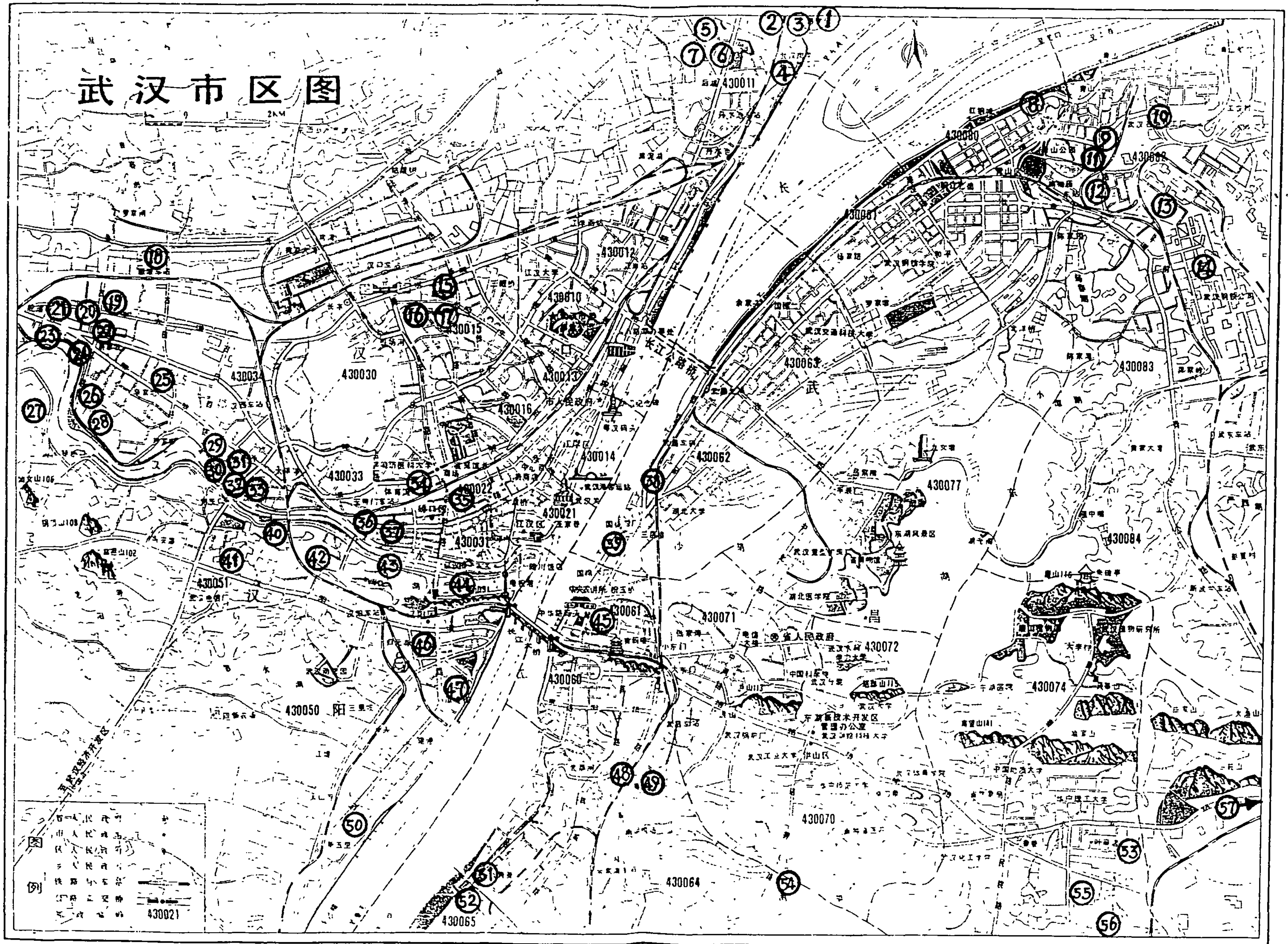
industrial sectors	discharge standards			
time of establishment	prior to end of 1988	01/1989-/061992	after 07/1992	series number
food processing	120	100	80	GB13457-92
paper making	350	100	100	GB3544-92
iron & steel	150	100	100	GB13456-92
textile	180	100	100	GB4287-92
synthetic NH4	150	100	100	GB13452-92

note: discharge limits are for individual background and are divided into quality grade one to three All the figures in the table are grade one limits on COD concentrations in industrial waste water discharge figure 1 Abatement cost and quantity of COD reduction



This mechanism is illustrated in figure 1. Both firms A and C were initially allocated Q2 permits. The cost of pollution control by firm A is lower than that by firm C If no trading of permits occurs, firm A will not have any incentive to reduce its pollution beyond Q1 While on the other hand, firm C will have to reduce its discharge up to Q3 disregarding its high level of control cost under a command and control framework At market clearing price of P, firm A would sell its permits Q2-Q1 in the market while firm C will have to buy Q3-Q2 permits so that its control cost at the margin equals P. In this way, the total control cost of the two firms is the lowest

Figure 1 Sketch Map of the Study Area and the Locations of Major Discharges



图上邮政编码依据武汉市邮政局
1991年11月编印的邮政编码图

制 图 武汉市勘测院地图制印厂

Table 5 COD Reduction and Cost Under Uniform Compliance

	waste water reduction t/day	COD reduction t	COD concentration mg/L	recycle rate	COD removal rate	COD concentr after treatment ppm	total cost 10,000 Y	among total cost: invest 10,000 Y	operation 10,000 Y	saving in fees 10,000 Y	unit cost Y/t COD
Wuhan Iron & Steel Co	700664	2197 95	42 97	0 60	0.20	34 38	5174 74	5250 25	552 21	627 72	23543 47
Wuhan Gourmet powder	1689	1570 95	4634 07	0 00	0 55	2085 33	138 17	96.48	90 45	48 76	879.51
Wuhan Medicals	4384	650 7	677.81	0 00	0.60	271.13	1137.25	353 53	855 98	72 27	17477.35
Dongfeng Paper Mill	2479	326.25	600.83	0.80	0.60	240.33	36 08	21.06	36.69	21 67	1105.91
Wuhan Dyestuff	1038	234 45	773 76	0 00	0 80	154 75	648 42	142 85	534.52	28 95	27657 18
Wuhan Paper Mill	5470	160 95	179 13	0 40	0.45	98.52	54.43	40 39	53 25	39 21	3381 87
Wuhan Organic Synthetics	503	154 5	1051 02	0 00	0 80	210 20	492 59	90.64	422 00	20 05	31882.93
Wuhan Household Chemicals	827	93.15	363 16	0.00	0 85	54 47	197.57	69 85	137.00	9 27	21210 17
Textile No 3501	1390	73.5	241 38	0 49	0 60	96.55	149 55	75.47	89.64	15 56	20346 91
Textile no 3551	628	58 2	362.62	0 00	0 70	108.79	86 96	40 42	51.74	5 19	14940 95
Hanyang Steel	2030	51 3	138.46	0 75	0.50	69.23	130 06	97 20	19 84	2 27	25352 37
YangtseChemicals	1418	36 6	117 87	0.00	0 60	47 15	280 31	97.11	183.20	0 00	76588 28
Wuhan Asphalt Felt	91	34.95	1165 00	0.00	0 90	116 50	267 89	30 98	241.57	4 66	76649 71
Wuhan Slaughter & Processing	696	32 7	151 39	0 00	0.85	22 71	107.31	37 10	71 29	1 07	32817 09
Wuhan Chemical Agent	261	31.35	387.04	0 00	0 85	58.06	104 94	34.54	73.62	3 21	33474.64
Wuhan Starch	212	30 9	664 52	0 50	0.60	265 81	64 41	36.00	33 72	3 57	20843 34
total/average	723782	5738 4	0 01				9070 68	6513 88	3446.69	903 43	15806 99

Table 4   16 Largest COD Dischargers

	invest in treatment yuan/t	opreational cost yuan/t	total industrial output 10,000 yuan	discharge fees paid 10,000 Y	total discharge 10,000 t	daily discharge t/day	quantity treated 10,000 t	abovelimit discharge t/day	COD total t
Wuhan Iron & Steel Co	171 5	0 10	801815	1749	34099	934219	33909	105616	14653
Wuhan Gourmet powder	78 8	0 02	14713	10	226	6192	21	6192	10473
Wuhan Medicals			21002	25	640	17534		10521	4338
Dongfeng Paper Mill	9 0	0.01	8427	52	362	9918	450	9918	2175
Wuhan Dyestuff	526.2	0 39	5362	21	202	5534	145	5534	1563
Wuhan Paper Mill			10283	78	599	16411		16411	1073
Wuhan Organic Synthetics			11700	14	98	2685		2685	1030
Wuhan Household Chemicals			5353	32	171	4685		4685	621
Textile No 3501	237 7	0 78	12490	5 2	203	5562	47	3342	490
Textile no 3551	617 3	0 04	11789	21	107	2932	58	2932	388
Hanyang Steel	399 7	0 07	24008	57	247	6767	1021	82	342
YangtseChemicals			4014	24	207	5671		0	244
Wuhan Asphalt Felt	10000	1.10	8080	1.2	20	548	1	0	233
Wuhan Slaughter & Processing			5265	16	144	3945		1589	218
Wuhan Chemical Agent			501		54	1479		1479	209
Wuhan Starch	471 1	0 11	2371	12	31	849	44	849	206
total			947173	2117 4[illegible]	37410	1024931	35696	171835	38256
57 total			1324251	2637.5	45183		39026		42034
16/57			71 53	80 28	82.80		91 47		91.01

Table 6 Costeffectiveness Compliance and COD Permit Trading

	waste water reduction t/day	COD reduction t	total cost 10,000 Y	among total cost invest. 10,000 Y	operation 10,000 Y	saving in fees 10,000 Y	unit cost Y/t COD	COD Permit Trade COD t	gains & expenses 10,000 Y	cost savings 10,000 Y
Wuhan Iron & Steel Co	0	0	0 00			0 00		-2197 95	-2198	2976 79
Wuhan Gourmet powder	2401	2233 48	151 66	114 05	106.94	69 33	679.0236	662.53	662 53	649 04
Wuhan Medicals	12374	1836 8	1676.56	678 99	1201 56	203 99	9127.66	1186 10	1186.10	646.78
Dongfeng Paper Mill	6942	913 5	48 05	49 14	59 57	60 66	526 0125	587.25	587.25	575.28
Wuhan Dyestuff	0	0				0 00		-234 45	-234 45	413 97
Wuhan Paper Mill	16411	482 85	179 28	99 78	89 31	9 80	3713 033	321 90	321.90	197 05
Wuhan Organic Synthetics	0	0	0 00			0 00		-154 50	-154 50	338.09
Wuhan Household Chemicals	0	0	0 00					-93 15	-93 15	104.42
Textile No 3501								-73.50	-73 50	76 05
Textile no 3551	2932	271 6	261.58	135 64	150 18	24.24	9630.966	213.40	213 40	38 78
Hanyang Steel	0	0	0 00					-51.30	-51 30	78.76
YangtseChemicals	0	0	0.00					-36 60	-36 60	243 71
Wuhan Asphalt Felt	0	0	0 00					-34 95	-34 95	232 94
Wuhan Slaughter & Processing	0	0	0 00					-32 70	-32 70	74.61
Wuhan Chemical Agent	0	0	0 00					-31 35	-31 35	73 59
Wuhan Starch	0	0						-30 90	-30 90	33 51
total	41060	5738 22	2317 14	1077.6	1607 56	368 02	4038 07	0 00	0 00	6753.37

Appendix C Cost Functions for COD Reduction from Industrial Waste Water[1]

waste water	dyeing[2]	paper:black water	paper. normal	slaught & process	food process
treatment technologies	activat mud de-water	alkalization	precipitation	activat mud disinfect	precipitation
capacity m^3/d	200 – 12000	300 – 2800	600 – 10000	500 – 1500	50 – 10000
inflow concentr mg/l	300 – 800	6000-160000	100 – 3000	500 – 2000	300 – 7000
outflow concen mg/l	100 – 300	0	20 – 800	60 – 300	100 – 4000
COD reduction %	50 – 70	100	45 – 90	80 – 90	20 – 70
invest function	$0.1892Q^{0.7860}$	$5.590Q^{0.9247}$	$0.02505Q^{0.8232}$	$1.915Q^{-0.5293}$	$0.03593Q^{0.9230}$
operation function	$1.240Q^{-0.3082}$	$27.73Q^{-0.2623}$	$1.915Q^{-0.5293}$	$8.233Q^{-0.5593}$	$0.9089Q^{-0.4394}$

continued

waste water	food processing	chemicals	chemicals	meterllurgy
treatment technologies	bio-chemical-disinfectation	activated mud	activat mud -dewater	precipitation
capacity m^3/d	300 – 4000	100 – 6000	100 – 50000	600 – 86500
inflow concentr mg/l	300 – 3000	200 – 500	300 – 4500	200 – 2700
outflow concen mg/l	100 – 500	40 – 60	100 – 500	40 – 200
COD reduction %	50 – 70	80 – 90	50 – 90	60 – 95
invest. function	$2.088Q^{0.4754}$	$0.8537Q^{0.611}$	$.342Q^{0.6289}$	$0.9966Q^{0.5620}$
operation function	$5.442Q^{-0.5241}$	$7.589Q^{-0.4612}$	$114.2Q^{-0.6732}$	$.871Q^{-0.5946}$

[1] unit : cost· 10,000 RMB yuan ; Quantity : m^3/d, unit cost yuan/m^3 。

[2] derived from 18 dying firms in Southern China 。