Tradable Permits for Environmental Protection: Case Study of an Integrated Steel Plant in India

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Abstract: Cost effective policies allow minimising the compliance costs associated to reaching a desired environmental quality target. In this paper a conceptual model has been developed to examine the compliance costs under an intra-plant emission trading system for a non-uniformly mixed assimilative pollutant. The model incorporates the number of emission sources, the concentration of pollutants emitted at each source, the marginal cost of abatement for each source, the transfer coefficient that relates emission at each source with the impact on ambient air quality, and the desired ambient air quality target. The model is applied to an integrated steel plant in India. Results of this study demonstrate that the emission trading is more cost effective than the existing regulatory system. Further, intra-plant trades would result in significant savings to the steel plant while securing an improvement in ambient air quality in the studied geographical area.

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Summary

There is a growing consensus amongst economists and policy makers that for the environmental policy to be effective there is a need to supplement the traditional command and control type of regulation with economic instruments. The main reasons for this move lie in the existing evidence on the growing levels of environmental degradation suggesting that the command and control type of regulation has not proved to be very effective in inducing the polluters to adopt pollution prevention and control and that the economic instruments are generally more cost-effective. Intuitively, cost effectiveness results from lower total abatement costs through a shift of the burden of abatement from high to low cost abaters.

Tradable permits for pollution control is one such economic instrument. Tradable permit systems can be of two types. The first type is inter-plant trading which allows emission trading among existing plants in a specified geographical area. The second type is that of intra-plant trading which allows different discharge points of a large firm to trade emissions among themselves. The latter offers the firm the option of reducing pollution loads beyond discharge limits at one or more discharge points and crediting it to other discharge points so that the pre-determined level of environmental standards or pollution reduction is met at a lower cost. This study attempts to design an intra-firm emission trading scheme for suspended particulate matter (SPM) in an integrated steel plant in India. Specifically we examine the costs of meeting the target emission standard for SPM for stationery sources of SPM in a steel plant, under the current regulatory system and the system of emissions trading among the emission sources under the common ownership, using the bubble concept.

A conceptual model has been developed to examine the compliance costs under an intra-plant emission trading system for a non-uniformly mixed assimilative pollutant. The model incorporates the number of emission sources, the concentration of pollutants emitted at each source, the marginal cost of abatement for each source, the transfer coefficient that relates emission at each source with the impact on ambient air quality, and the desired ambient air quality target. The model is applied to an integrated steel plant in India. Results of this study demonstrate that the emission trading is more cost effective than the existing regulatory system. Further, intra-plant trades would result in 4.7 per cent saving to the plant while securing an improvement in ambient air quality in the studied geographical area. These point towards the need to implement intra-plant trading in identified integrated steel plant in India.

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TRADABLE PERMITS FOR ENVIRONMENTAL PROTECTION: CASE STUDY OF AN INTEGRATED STEEL PLANT IN INDIA

1. Introduction

There is a growing consensus amongst economists and policymakers that for the environmental policy to be effective there is a need to supplement the traditional command and control type of regulation with economic instruments. The main reasons for this move lie in the existing evidence on the growing levels of environmental degradation suggesting that the command and control type of regulation has not proved to be very effective in inducing the polluters to adopt pollution prevention and control and that the economic instruments are generally more cost-effective.[1] Intuitively, cost effectiveness results from lower total abatement costs through a shift of the burden of abatement from high to low cost abaters.

Tradable permits for pollution control is one such economic instrument. Tradable permit systems can be classified into two groups. The first type is inter-plant trading which allows emission trading among existing plants in a specified geographical area; the second is that of intra-plant trading, which allows different discharge points of a large firm to trade emissions among themselves. The latter offers the firm the option of reducing pollution loads beyond discharge limits at one or more discharge points and crediting it to other discharge points so that the pre-determined level of environmental standards or pollution reduction is met at a lower cost. This study attempts to design an intra-firm emission trading scheme for an integrated steel plant in India. Trading scheme is designed for suspended particulate matter (SPM), a toxic air pollutant emitted by the steel plants which can alter the immune system and can cause serious health hazards. The main purpose of this exercise is to assess the potential savings associated with implementing economic, rather than current regulatory approaches to abate SPM in a local airshed. Specifically we examine the costs of meeting the target emission standard for SPM for stationery sources of SPM in a steel plant, under the current regulatory system and the system of emissions trading among the emission sources under the common ownership, using the bubble concept.[2] The paper concludes by drawing out some of the policy implications of this analysis.

2. The Analytical Model

What constitutes an emission trading system depends on the attributes of pollutants being controlled. To be consistent with the cost effectiveness objective of the emission control policy, different trading schemes would be required for different types of pollutants. For instance, for pollutants that are uniformly mixed in the atmosphere, trading between two emission sources can take place on a one-to-one basis, as a unit emission of pollutant from any discharge point in an airshed would contribute to ambient air quality in the same manner. That is, in the case of uniformly mixed pollutants, the ambient concentration of the pollutant depends on the total amount of pollutant discharged, but not on the location of discharge points. Thus a unit reduction in emission from any source within an airshed would have the same effect on the ambient air quality. However, the instrument design is somewhat different when pollutants are not uniformly mixed in the atmosphere such as the SPM, which as noted earlier is also the focus of this study. In the case of SPM, trading cannot be on one-to-

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[1] See Bohm and Russell (1985), Baumol and Oates (1988), and Montgomery (1972).

[2] The bubble concept allows various polluters in a geographical area – with varying abatement costs – to jointly abate a predetermined quantity of pollutants. See Atkinson and Tietenberg (1982).

one basis, as the location of the discharge points (including the stack height) matters – all sources do not contribute to ambient air quality in the same manner. Their contribution depends on each source's emission diffusion characteristics with respect to each monitored receptor. This implies that one unit of extra reduction (over and above the legislated level) by source ‘a’ may not necessarily be equivalent to one unit of excess emission (over the legislated level) by source ‘b’ if the emission diffusion characteristics or transfer coefficients for sources ‘a’ and ‘b’, associated with a given receptor are not the same.

The cost effective allocation of a non-uniformly mixed assimilative[3] pollutant is that allocation which minimises the cost of pollution control subject to the constraint that the target concentration level of pollutant in the ambient air is met at all receptors in the airshed. This can be represented as[4]:

$$Min \sum_{j=1}^{J} C_j\,(r_j) \qquad (1)$$

subject to

$$A_i \geq \sum_{j=1}^{J} d_{ij}\,(e_j - r_j) \qquad i = 1,\ldots,I \qquad (2)$$

$$r_j \geq 0 \qquad j = 1,\ldots..,J \qquad (3)$$

Here C_j is the cost of emission reduction and r_j is the amount of emission reduction that the j^{th} source has to achieve, and J is the number of sources (discharge points) to be regulated. As r_j increases, the marginal cost of control is expected to increase. e_j is the emission rate of the ^{jth} source that would prevail if the source failed

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[3] For assimilative pollutants, the capacity of the environment to absorb them is relatively large compared to their rate of emission, such that the pollution level in any year is independent of the amount discharged in the previous years. In other words, assimilative pollutants do not accumulate over time.

[4] See Tietenberg (1985).

to control any pollution at all. A_i is the level of air quality obtained at receptor i when the firms are in compliance with the current point source standards. d_{ij} is the transfer coefficient which measures the contribution of one unit of SPM emissions from source j to concentrations of SPM in the ambient air measured at receptor i. The transfer co-efficient expresses the diffusion characteristics of the pollutants and is a function of such factors as average wind velocity and direction, temperature, the locations of sources and receptors, as well as source stack heights. In the absence of trading, r_j would be equal to e_j minus the prescribed (legislated) emission standard for source j.

A cost effective allocation must satisfy the Kuhn-Tucker conditions for optimum allocation; the Kuhn-Tucker conditions for the above problem are:

$$\partial C_j(r_j)/\partial r_j - \sum_{i=1}^{I} d_{ij}\lambda_i \geq 0 \qquad j = 1,\ldots,J \qquad (4)$$

$$r_j[\partial C_j(r_j)/\partial r_j - \sum_{i=1}^{I} d_{ij}\lambda_i] = 0 \qquad j = 1,\ldots,J \qquad (5)$$

$$A_i \geq \sum_{j=1}^{J} d_{ij}(e_j - r_j) \qquad i = 1,\ldots,I \qquad (6)$$

$$\lambda_i[A_i - \sum_{j=1}^{J} d_{ij}(e_j - r_j)] = 0 \qquad i = 1,\ldots,I \qquad (7)$$

$$r_j \geq 0,\ \lambda_i \geq 0 \qquad \begin{matrix} j = 1,\ldots,J \\ i = 1,\ldots,I \end{matrix} \qquad (8)$$

Equation (4) states that in a cost effective allocation for SPM or any other pollutant falling in the class of non-uniformly mixed assimilative pollutants, each source should equate its marginal cost of emission reduction with a weighted average of the marginal cost of concentration reduction (λ_i) at each affected receptor. The weights are the transfer coefficients associated with each receptor. That is, for SPM, it is not the marginal costs of emission reduction that are equalised across sources in a cost-effective allocation (as would be the case for uniformly mixed assimilative pollutants), rather it is the marginal costs of concentration reduction at each monitored receptor that are equalised.

3. Abatement Cost Functions

Constraints on data required for estimating economic cost functions led us to use engineering cost functions for SPM abatement. In deriving the cost of SPM abatement, only the operating costs of pollution abatement are considered. Capital costs of abatement, devices are treated as sunk costs since the model is based on the existing clean up operations at the steel plant. Annual operating cost of SPM abatement is taken to be a function of the volume of SPM laden gas and the concentrations of SPM in the gas before and after the abatement (Pandey, 1998). This can be written as:

operating cost = f (volumetric flow of gas, concentration of SPM in the gas before subjected to treatment, concentration of SPM in the gas after the treatment).

The abatement cost is expected to vary in the following manner.

$$AC = \{Q\,(SPM_{bt} - SPM_{at})\}^{\mu} \qquad (9)$$

where, AC = abatement cost (Rs.)

Q = volumetric flow of gas (Nm^3/day)

SPM_{bt} = concentration of SPM before treatment (mg/Nm^3)

SPM_{at} = concentration of SPM after treatment (mg/Nm^3)

μ = different variable for every abatement facility.

the value of μ is a constant and is expected to lie between 1 and e (2.71).

The abatement cost function defined by (9) provides means to compute the marginal cost of SPM abatement over a range of SPM concentration for pollution control devices currently in use at the steel plant. The marginal cost is the change in total cost at the margin arising from removing any additional unit of pollutant. In brief, the change in AC at the margin arising from a unit change in $Q(SPM_{bt} - SPM_{at})$ is defined as marginal cost (MC).

$$MC = \frac{dAC}{dR}$$

where, $R = Q\ (SPM_{bt} - SPM_{at})$

4. Steel Plants: Sources of and Techniques for SPM Abatement

The production of steel in India is dominated by a number of large integrated iron and steel plants in the public sector under the control of the Steel Authority of India Limited (SAIL). There are five main production stages in an integrated steel plant: coke oven batteries; blast furnace; steel melting shop (SMS); casting of steel and rolling mills.

An integrated steel plant generates environmental pollution at each stage of the production process. SPM is an important air pollutant released from steel plants in India. The main sources of SPM emissions in a steel plant are: coke ovens, sinter plants, power plants, refractories, blast furnace, and SMS. Steel plants in India have mainly been using end of the pipe control equipment for controlling air pollution (Kakkar, 1998). Equipment for air pollution abatement includes various types of water scrubbers, cyclones, bag filters and electronic precipitators (ESPs). Minimal national standards (MINAS) have been specified for various pollutants which apply to each discharge point within the steel plant (table 1). The MINAS is defined as the maximum concentration of pollutants allowed per unit of gas emitted.

Table 1. Stack emission norms for SPM

Process	Norm (mg/Nm^3)
Coke oven	50
Blast furnace	150
SMS	400*
Refractories	150
Sinter plant	150
Power plant	150**

Source: CPCB (1988).

* During oxygen lencing, otherwise norm is 150 mg/Nm^3.
** For power plants less than 200 MW, emission norm is 350 mg/Nm^3.

5. The Data

It may be noted here that though the analytical model presented in section 2 can be used to design both inter-plant as well as intra-plant emission trading, in this paper, however, the model is applied to examine intra-plant trading in an integrated steel plant. The Bokaro Steel Plant (BSP) is selected as a case study. The data has been obtained from the plant by means of a questionnaire, and several rounds of personal discussions with the staff of the environment management division at the BSP as well as the corporate office of SAIL at New Delhi.

Owing to the nature of SPM (non-uniformly mixed pollutant) an air quality modelling technique is used to determine the ambient air quality that would be obtained in the baseline emission scenario in the local airshed (20 x 20 km area around the steel plant) and in the emissions trading scenario. The baseline emission scenario refers to the situation in which the prescribed (legislated) point source emission standards are met at all the discharge points at the steel plant. As noted earlier, the estimates of transfer coefficients for each discharge point for the receptors affected by its emissions and the relative costs of abatement of SPM across emission sources would determine the final trading outcome. These have been obtained as follows.

The effect of emissions from various discharge points in the plant on the local ambient air quality is determined using the *Gaussian Plume* model. The source-receptor-pollutant transfer coefficients are computed from the calculated contributions of each source to the ambient concentrations at each of the 8 receptors in the airshed. The model was run to obtain the 24-hourly average ground level concentrations of SPM for the month of December. Information on geographic location and configuration of various discharge points (stack top diameter, stack height) [see annexure 1], characteristics of SPM laden gas (velocity, temperature and volumetric flow), and rate of emission from various discharge points is obtained from the BSP.

The costs of SPM abatement for various sources is obtained from the SPM abatement cost functions. Engineering cost functions of SPM control are derived from the plant level data on the financial costs of abatement obtained from the BSP.

6. Results and Discussion

Current total abatement of SPM in BSP from the six sources considered in the study is 1797.15 tonnes per day (table 2) at an average cost of abatement of Rs. 412 per ton. The distribution of total SPM abated by these sources is given in annexure 2. Marginal costs of SPM abatement vary from as low as Rs. 42.1 per kg to Rs. 2486.4 per kg of SPM abated. Of all the sources of SPM considered in the study, the *Sinter plant* has the highest and thermal power plant (TPP) has the lowest abatement cost per kg of SPM.

Table 2. Quantity and cost of SPM abated under alternative scenarios

Scenarios	SPM abated (tons per day)	Cost of SPM abated (lakhs[$] per year)	Cost saving with trading*	Ground level concentration at worst receptor mg/Nm^3	Improvement in air quality
Base-case scenario	1849.9	2856.21	-	183.6	-
Present scenario	1797.15	2703.77	-	-	-
Trading Scenario	1849.9	2721.33	4.72%	170.0	7.4%

* With respect to base-case scenario.

[$] 1 lakh is equivalent to 100 thousand.

Compliance with the existing point source emission norms at the sources considered in the study involves the abatement of 1849.9 tons of SPM per day at a total abatement cost of Rs. 2856.21 lakh per year (see table 2). The distribution of total SPM abated in base-case scenario is given in annexure 3.

Before we discuss the cost implications of the trading scenario it must be recalled that this study considers only the operating costs of abatement. Capital cost of abatement is taken as sunk cost (section 3). This implies that abatement equipments are exogenously given. Abatement efficiency of these equipments is, therefore, a function of their design efficiency and vintage. This acts as an additional constraint on the optimal trading.

For the base–case ambient air quality levels, the cost-effective allocation of abatement responsibility among various emission sources obtained from the model is presented in table 3. The most important observation that can be made on the basis of these results is that the *Sinter plant* having the highest abatement cost source is allowed to emit more (at both the stacks), at 300 mg/Nm^3 against the legislated level of 150 mg/Nm^3. The other five sources considered in this study would compensate for it by abating more than their legislated requirements.

Table 3. Trading Scenario

Source*	Base-case (mg/Nm^3)	After trading (mg/Nm^3)	No. of Stacks
TPP	150	100	1
CPP	150	120	1
Kiln	150	75	2
BF	150	135	3
SMS	400	375	1
Sinter	150	300	2

* TPP has the lowest abatement cost per kg of SPM while Sinter has the highest.

Column 3 of table 2 presents the estimates of cost of SPM abatement for the base-case and present scenarios as well as the trading scenario. Lower abatement cost under the trading scenario reiterates the point that the current regulatory approach is relatively more expensive. The cost saving to BSP under the trading scenario works out to 4.72 per cent of its annual operating costs of air pollution control. Some may argue that these savings appear rather small to favour implementation of tradable permits which are generally associated with significant enforcement costs. Two things must be pointed out here. First, the cost savings reported above are an underestimate because the trading possibilities are based on the existing clean up devices, the choice of which are largely governed by the current legislation. Second, costs of implementing intra-plant emission trading would be much lower than in the case of inter-plant emission trading. Thus taking into account the cost of implementation of intra-plant trade and the potential savings in capital costs of emission control the net costs savings under emissions trading would be higher than those reported here. Thus our findings support the point that intra-plant emissions trading offers the opportunity to realise substantial reduction in SPM abatement costs as well as improvement in ambient air quality (7.4 per cent improvement in air quality at the worst receptor[5]) thus contributing to enhancement of social gains.

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[5] In terms of ambient air quality.

7. Policy Implications

Results of this study have demonstrated that emission trading is more cost effective than the existing regulatory system. Results show that intra-plant trading would result in significant savings to the industry, while securing the improvement in ambient air quality in the studied geographical area. These point towards the need to implement intra-plant trading in the identified integrated steel plants in India. Implementing emission trading would, however, require a reform of the existing regulatory framework.

8. Issues for Future Research

The study has identified at least two areas for research follow-up.

- ♦ Investigating the possibilities of intra-plant trading for other steel plants and other pollutants. It may also be worth exploring the cost effectiveness of introducing inter-plant permit trading.
- ♦ Examining the issues in compatibility of intra-plant emission trading with existing laws, legal sanctions, and fines.

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Annexure 1: Sources of emissions, physical characteristics, and flow rate of flue gas

Source	No. of Stacks	Norm of PM (mg/Nm^3)	Pollution control equipment	Stack height (m)	Stack top diameter (m)
1. Sinter	2	150	Multicylones on exhaust side; and Venturi Scrubbers on discharging side	100	10
2. Kiln	2	150	ESP	80	2.76
3. SMS	1	400	Venturi Scrubbers	100	4.3
4. Power plant	2				
TPP	1	150	ESP	180	6

	Source	No. of Stacks	Norm of PM (mg/Nm^3)	Pollution control equipment	Stack height (m)	Stack top diameter (m)
	CPP	1	150	ESP	180	6
5.	Blast Furnace	3	150	Cyclone	50	8.2

Annexure 2: SPM abatement, total and marginal costs (Present emission scenario)

	Source	Volumetric flow rate, (Nm^3/day)	SPM abated (tons per day)	μ	Total cost of SPM abatement (Rs. lakh/year)	Marginal cost of SPM abatement (Rs./kg)
1	Sinter plant (exhaust)	22259102.0	28.63	1.94	367.12	2486.4
2	Sinter Plant (discharge)	17800358.0	22.89	1.94	293.58	2486.4
3	Kiln	17046771.2	99.87	1.54	154.42	238.5
4	SMS	25870176.0	87.47	1.83	856.11	1786.7
5	TPP	32719660.8	973.61	1.24	329.62	42.1
6	CPP	30833912.0	527.63	1.38	492.37	128.6
7	Blast Furnace	45937437.7	57.05	1.73	210.54	637.4
	Total		1797.15		2703.77	

Annexure 3: SPM abatement, total and marginal costs
(Base-case scenario)

	Source	Volumetric flow rate, (Nm^3/day)	Norms for SPM (mg/ Nm^3)	SPM abated (tons per day)	μ	Total cost of SPM abatement cost (Rs. lakh/year)	Marginal cost of SPM abatement (Rs./kg)
1	Sinter plant (exhaust)	22259102.0	150	31.56	1.94	443.69	2725.3
2	Sinter Plant (discharge)	17800358.0	150	25.24	1.94	354.82	2725.3
3	Kiln	17046771.2	150	98.55	1.54	151.28	236.8
4	SMS	25870176.0	400	84.72	1.83	807.75	1740.4
5	TPP	32719660.8	150	972.04	1.24	328.96	42.1
6	CPP	30833912.0	150	581.28	1.38	562.67	133.4
7	Blast Furnace	45937437.7	150	56.50	1.73	207.04	632.9
	Total			1849.90		2856.21	