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Comparing the cost effectiveness of market-based policy instruments versus regulation: the case of emission trading in an integrated steel plant in India

RITA PANDEY
Fellow, National Institute of Public Finance and Policy, 18/2, Satsang Vihar Marg, Special Institutional Area, New Delhi, 110 061 India.
Email: rita@nipfp.org.in

GEETESH BHARDWAJ
Rutgers, The State University of New Jersey, USA.

ABSTRACT. Cost-effective policies allow for minimizing the compliance costs associated with 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 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.

1. Introduction

There is a growing consensus amongst economists and policy makers that for environmental policies to be effective there is a need to supplement traditional command and control type of regulation with economic instruments. The underlying reason for this move lies in existing evidence on growing levels of environmental degradation suggesting that the command and control type of regulation has not proved to be very effective in inducing polluters to adopt pollution prevention and control and that

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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. Though a range of economic instruments have been discussed in the literature, two have received greater attention from both economists and policy makers – effluent or emission charges and tradable emission/discharge permits. In this paper attention is focussed on the latter approach.

Tradable permit systems can be introduced in two ways. The first type is inter-plant trading which allows emission trading among existing plants in a specified geographical area. The second is 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 point and crediting it to other discharge points so that pre-determined levels of environmental standards or pollution reduction are met at a lower cost. This study attempts to evaluate the cost effectiveness of an intra-firm emission trading scheme for an integrated steel plant in India. A trading scheme is designed for suspended particulate matter (SPM), a toxic air pollutant emitted by steel plants which can alter the human immune system and can cause serious health hazards. The main purpose of this exercise is to assess the potential savings associated with implementing market-based regimes, rather than current regulatory approaches to abate SPM in a local airshed. Specifically, we compare the cost of meeting the target emission standards for SPM from stationery sources in a steel plant under the current regulatory system and a system of emissions trading among emission sources under one ownership. The study employed the bubble concept of Atkinson and Tietenberg (1982) to conduct comparative analysis of cost effectiveness.[2] The paper concludes by drawing out some policy implications of this analysis.

2. The steel sector in India and the Bokaro Steel Plant

India is the tenth largest steel producer in the world. The industry represents over Rupees (Rs)[3] 900,000 million of capital (Pandey, 2000). Production of finished steel in India has increased from 14.33 million tons in 1991–1992 to 29.27 million tons in 2000–2001 (Government of India, 2002). Steel production in India is expected to reach 38.6 million tons in 2010.

Among the 16 most polluting industries notified by the Central Pollution Control Board (CPCB) in India – which account for about 30 per cent of the total value of industrial production and 20 per cent of total industrial employment – the iron and steel industry is the largest, accounting for almost a third of both value of production and employment of the 16 most

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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).

[3] US$ 1 = 48 rupees, approximately.

polluting industries, and the second largest air polluter, emitting nearly 32 per cent of total industrial air pollution load (Pandey, 2000).[4]

As steel making involves multiple processes with environmental implications at various stages, an expected increase of 34 per cent in production during 2000–2010 could lead to considerable increase in pollution from this industry, particularly if appropriate policies and measures to control pollution are not put in place. The production of steel in India is dominated by a number of large integrated iron and steel plants in the public sector under the direct control of the Steel Authority of India Limited (SAIL). The Bokaro Steel Plant (BSP), which is one of the large integrated steel plants of SAIL has been selected as a case study in this paper.

The BSP is located on the southern bank of the Damodar river along the Dhanbad-Ranchi highway at a 40 kilometre distance from the Dhanbad Railway Station in the Bihar province of India. Bihar is located in the north-eastern plains of the country. BSP started operation with a capacity of 2.5 million tons per annum in 1973–1974. The total installed capacity (hot metal production) of BSP at present is 4 million tons.

3. Sources of and techniques for SPM abatement in steel plants

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 its 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 furnaces,* 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 include various types of *water scrubbers, cyclones, bag filters,* and *electrostatic precipitators (ESPs)*.

The Environment Protection Act, 1986 (EPA, 1986) has specified minimal national standards (MINAS) 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. Each emission source is expected to conform to the specified emission standards. Under the EPA (1986), those exceeding the specified standards are liable to be imprisoned for a period ranging between 18 months and six years and/or fined up to a maximum of Rs. 5,000 per day. The Act, however, does not make any distinction between the extent of violation and the term of imprisonment or the amount of fine. Non-compliance on a continuous basis can lead to closure of the plant. This, however, is rare due to poor enforcement.

4. Emission trading and cost efficiency

Since an environmental pollution problem arises due to the absence or inadequate pricing of the environment, it can be corrected by establishing

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[4] Industrial pollution load refers to the pollution load of the 16 most polluted industries identified by the CPCB.

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**

Notes:
*During oxygen lencing, otherwise the norm (maximum allowed) is 150 mg/Nm^3. Mg and Nm^3 are milligram and normal metre cube, respectively.
**For power plants less than 200 MW, emission norm is 350 mg/Nm^3.
Source: CPSB (1988).

the missing market of environmental quality. Dales (1968) suggested that, consistent with the environmental goal, the regulatory authority could distribute a certain number of emission permits among the sources, and the free market would set a price for the permit that ensures cost efficiency in pollution abatement, that is, firms with lower cost of controlling emissions will abate more and sell off their permits to those with higher cost of abatement.

Strictly speaking however, the optimal level of pollution abatement should be determined by the equality of the marginal social benefit of abatement with the marginal social cost of abatement. Since the social benefit function is not correctly estimable, the objective of the regulator is generally seen as the attainment of a predetermined environmental quality at the least costs using a combination of economic instruments and the current purely regulatory system.

Tradable emission permits are a tool for market creation for environmental resources. What constitutes an emission trading system depends on the attributes of the pollutants being controlled. To be consistent with the cost effectiveness objective of the emission control policy, different trading schemes would be required for various 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 the 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 is the focus of this study. In the case of SPM, trading cannot be on a one-to-one basis, as the location of the discharge points (including the stack height) matters since different sources do not contribute to ambient air quality in the same manner. The contribution of various sources depends on each source's emission diffusion characteristics with respect to each 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 source 'a' and 'b' are not the same.

The cost effective allocation of a non-uniformly mixed assimilative[5] 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[6]

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

subject to

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

$$R_j \geq 0 \qquad\qquad j = 1, \ldots, J \tag{3}$$

where C_j is the cost of emission reduction and r_j is the amount of emission reduction that the jth 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 to reduce any pollution at all. A_i is the level of air quality obtained at receptor i when the firm is 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 coefficient 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. Equation (2) represents a constraint on trading. It allows trade among emission sources as long as they do not violate the ambient air quality (A) at any monitored receptor. A is taken to be the level of air quality obtained at a given receptor when the steel plant is in compliance with the current point source standards. This is because in India, although both source specific and ambient air quality standards are laid down, actual enforcement relates mostly to source standards specified for individual polluters. Furthermore,

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[5] 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.

[6] See Tietenberg (1985).

the ambient and source standards are laid down independently, unrelated in terms of the volume of pollution-generating activities. Hence, it is quite conceivable that in many cases ambient air quality could not be met despite a high degree of compliance among individual polluters.

A cost effective allocation must satisfy the first-order *Kuhn–Tucker* conditions for the cost minimization problem specified in equations (1)–(3) above. These are

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

$$r_j \left[\delta C_j(r)/\delta r - \sum_{i=1}^{I} d_{ij}\lambda_i \right] = 0 \quad j = 1, \ldots, J \tag{5}$$

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

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

$$\begin{aligned} r_j \geq 0, \lambda_i \geq 0 \qquad & j = 1, \ldots, J \\ & i = 1, \ldots, I \end{aligned} \tag{8}$$

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 equalized 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 equalized.

The condition says that the larger the dispersion coefficients of a source (d_{ij}), the larger should be the reduction of emissions at that source. Evidently, the onus of capturing the spatial feature of the pollutant falls on the design of the permit market. The literature in this field (Montgomery, 1972; Atkinson and Tietenberg, 1982; 1987; Krupnick *et al.*, 1983; McGartland and Oates, 1985) has suggested various permit systems to account for location characteristics of a pollutant. Among the different trading systems suggested, the *non-degradation offset* (NDO) trading rule of Atkinson and Tietenberg (1982, 1987) offers the ideal trading rules. The NDO system of emission trading is governed by the meteorological model, while maintaining the total source emissions at pre-trade level, and not violating existing ambient air quality regulations.

As mentioned earlier, the cost-effective allocation of a non-uniformly mixed assimilative pollutant is that allocation which minimizes the cost of pollution control subject to the constraint that target concentration levels are met at all receptors in the bubble. In other words, the cost-effective allocation equalizes the marginal cost of concentration reduction at each receptor location. The marginal cost of concentration reduction depends on the marginal cost of emission reduction of a source and the transfer coefficient of the given source for a receptor location. Sources with relatively higher transfer coefficients for a given receptor, and relatively lower abatement costs would get higher abatement responsibility, whereas sources with relatively lower transfer coefficients and higher abatement costs would get lower abatement responsibility. If there are n sources which affect only one receptor, then the amount of emission reduction each source has to undertake can be obtained by equating the marginal cost of concentration reduction across n sources for the given receptor using equation (7). When a source affects more than one receptor, it is quite likely that the affected receptors may require the source to abate emissions by different amounts. In such a scenario the highest amount of emission reduction that a source is required to undertake by the affected receptors, will have to be met. This would take care of emission reduction requirement of this source for any receptor that it affects.

To illustrate, let the emission sources be A, B, C, and D, and the receptors be 1, 2, and 3. Each emission source will have some transfer coefficient for each receptor it affects. Let us say sources A and B affect receptor 1, source C affects receptor 1 and 2, and source D affects all three receptors. Each source has a marginal abatement cost (MC) schedule, which when divided with the transfer coefficient for this source associated with a given receptor gives the marginal cost of concentration reduction (MC/d_{ij}) at each of the receptors. Given the target air quality at receptor 1, abatement responsibilities of sources A and B can be obtained from equation (7). Abatement responsibilities so obtained would lead to both the target air quality at receptor 1 and minimization of cost of concentration reduction at receptor 1 with respect to sources A and B. Determining abatement responsibilities for sources C and D would be a little complex as they affect more than two receptors. Suppose that receptor 1 requires source C to reduce emissions by 15 units while receptor 2 requires it to reduce emissions by 20 units. It is obvious that a single source cannot reduce emissions by different amounts for two receptors. Thus it will have to reduce its emissions by the highest amount, that is 20 units. It can, however, trade its abatement responsibility with source D for receptor 2, if the abatement cost at D is relatively lower and transfer coefficients are relatively higher. Abatement responsibilities between C and D for receptor 2 can also be obtained with the help of equation (7).

5. SPM abatement cost function

From an engineering perspective, abatement is generally referred to as the installing and operating processes which reduce influent concentrations to target emission levels, where influent is the SPM laden gas from production before treatment and effluent is the residual emitted after the treatment. However, besides installing an effluent treatment plant at the end of the main production process, a pollution control process can also be installed within the main production plant at the various stages of production. In-plant pollution abatement costs are not considered in this study primarily due to lack of data on such costs as well as due to the problems of measuring the level of pollution removal attributable to these costs. Hence, abatement cost refers to only end-of-pipe abatement.

The effluent treatment plant can be considered as a production activity, which has a production function as does any other production activity. For a cost-minimizing firm, a cost function relating the effluent treatment cost to the level of treatment can be derived by minimizing abatement cost subject to the production function (Pandey, 1998). Constraints on data required for estimating economic cost functions led us to use engineering cost functions for SPM abatement. These are different from economic or behavioural cost functions. Theoretically, economic cost functions may be better. It is unclear, however, how much they would change the results of the model. Moreover, Mehta *et al.* (1994) note that in developing countries like India, engineering estimates of abatement costs are likely to be more accurate as firms do not maintain data on various components of abatement costs for each of the control facilities. In deriving the cost of SPM abatement, only the operating costs of pollution abatement were considered. Capital costs of abatement devices were treated as fixed sunk costs as the model was based on existing clean-up operations at the steel plant, which are governed by the current legislation. It must be noted that investment patterns in abatement technology could be very different for the plant if emission trading was allowed. It is also important to note that the generation of capital cost data under the trading scenario could be based only on an engineering analysis of a hypothetical plant/situation with no 'field' experience. Hence the actual cost effectiveness of such control technologies could vary by a wide margin when applied to the plant. For this reason an attempt to include capital cost in the analysis was not made. It must also be mentioned here that non-inclusion of capital costs in the trading scenario may lead to under estimation of the potential savings associated with emission trading.

Annual operating costs of SPM abatement were 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

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

This specification was developed in consultation with environmental engineers in BSP who actually operate these plants. The study has taken into account six SPM emitting sources in the plant and four techniques for abating SPM. The techniques for removing SPM considered in the study were: *Bag filter, electrostatic precipitator, venturi scrubbers,* and *wet scrubbers*. Variation in operating costs across abatement facilities was mainly based on differences in the quantity of electricity used, equipment maintenance costs, and labour cost. It may be argued that when capital equipment are exogenously given, what measures would be used to reduce SPM by those abatement facilities whose abatement responsibilities are increased in the trading scenario. To meet the additional emission control responsibilities, one or more of these measures would be used by the abatement facilities: operation of abatement equipment at its full potential/efficiency; better maintenance and smooth and continuous operation of abatement equipment; and better maintenance of production facilities.

The engineers expected the abatement cost to vary in the following manner

$$AC = \{Q(SPM_{bt} - SPM_{at})\}^{\propto} \tag{9}$$

where:

AC = abatement cost (Rs.)
Q = volumetric flow of gas (Nm^3/day)[7]
SPM_{bt} = concentration of SPM before treatment (Mg/Nm^3)
SPM_{at} = concentration of SPM after treatment (mg/Nm^3)
$\propto$ = different parameter for every abatement facility.

$\propto$ has been computed for each emission abatement facility from equation (9).

Using the abatement cost function defined by (9) the marginal cost of SPM abatement for different levels of influent or effluent concentrations of SPM for various pollution control devices currently in use at the steel plant are computed. The marginal cost is the change in total cost at the margin arising out of the removal of an additional unit of pollutant.[8]

6. The data

The BSP has been selected as a case study. Data for this have been obtained from the plant through a questionnaire with some rounds of discussion with the staff of the environment management division in BSP, as well as those of the corporate office SAIL, New Delhi.

Owing to the nature of SPM (non-uniformly mixed pollutant) an air-quality modelling technique was used to determine the ambient air quality that would be obtained in the baseline emission scenario in the local airshed (20 × 20 km area around the steel plant) and in the emissions-trading scenario. The baseline emission scenario refers to a situation in

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[7] Nm^3 = Normal meter cube.

[8] 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, $R = Q(SPM_{bt} - SPM_{at})$ or SPM load abated. Marginal cost is given by partial derivative of AC with respect to R (Goldar and Pandey, 2001). Therefore

$$\frac{dAC}{dR} = \frac{1}{Q}. \propto (\mathrm{SPM}_{bt} - \mathrm{SPM}_{at})^{\propto - 1}$$

which the prescribed (legislated) point source emission standards are met at all discharge points in the steel plant. As noted earlier, 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 local ambient air quality was determined using the *Gaussian Plume* model (see appendix 1). To implement the model required data on point sources and meteorological conditions. Point source information was obtained from the BSP. For each point source, data included: geographic location and configuration of various discharge points (stack top diameter, stack height) (see appendix 2); characteristics of SPM laden gas (velocity, temperature, and volumetric flow); and rate of emission from various discharge points. Meteorology governs the dispersion of pollutants after they are emitted into the atmosphere. Meteorological data on wind direction, wind speed, stability class, and mixing height were obtained from BSP and CPCB. The month of December, which is a critical month in northern India where BSP is located, was selected as the study period.[9] The model was run to obtain a 24-hourly average ground level concentration of SPM for this month. Information on wind direction and speed was provided in the form of a wind rose. The wind rose is indicative of the frequencies of different wind directions and frequencies of groups of wind speeds in these directions. The predominant wind directions are north-west and north. An average wind speed of 2.2 m/s was observed during the period with occurrence of wind speed class 1 (0.6 to 2.0 m/s) and wind speed class 2 (2.1 to 4.0 m/s) for about 48 per cent and 47 per cent of the time, respectively.

Data on atmospheric stability were generated for four classes: (i) unstable, (ii) neutral, (iii) light stable, and (iv) stable using the *Pasqill–Gifford* scheme (CPCB, 1998). The typical diurnal variation of *Pasqill–Gifford's* stability for winter was used. During the daytime mostly unstable conditions were prominent, while conditions during night hours varied from light stable to stable. The frequencies of unstable and light stable conditions were 46 per cent and 34 per cent, respectively. Some occurrence of neutral conditions were also noticed, particularly during the evening. Two different sets of mixing height for various stability conditions were used. Mixing heights of 1,200, 1,000, 800, and 200 meters for unstable, neutral, light stable, and stable conditions respectively were considered as the first set of data. Values for the second set were 1,500, 1,200, 800, and 500 meters. The source–receptor–pollutant transfer coefficients were computed from the calculated contributions of each source to the ambient concentrations at each of the eight receptors in the airshed.

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[9] Owing to meteorological conditions, ground level concentrations of SPM in December as monitored at the receptors were among the highest concentrations observed in any other month in the study area. Thus, trading scenario obtained from this exercise would ensure that the ambient air quality standard is not violated at any time during the year.

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

Senarios	*SPM abated (tons per day)*	*Cost of SPM abated (Rs million per year)*	*Cost saving with trading**	*Ground level concentration at worst receptor mg/Nm^3*	*Improvement in air quality*
Base-case scenario	1,849.9	285.62	–	183.6	–
Present scenario	1,797.15	270.38	–	–	–
Trading Scenario	1,849.9	272.13	4.72%	170.0	7.4%

Note: *With respect to base-case scenario.

The costs of abatement of SPM for various sources was obtained from the engineering cost functions for various abatement facilities. These engineering cost functions of SPM control were derived from plant-level data on the financial costs of abatement obtained from the BSP.

7. Results and discussion

Using this model, two types of estimates were produced and compared for alternative scenarios, presented in table 2. First, costs of SPM abatement for all sources considered were estimated. Second, a set of emission controls for various emission sources that simultaneously minimize the overall abatement costs and meet the target SPM concentrations at all receptor locations were obtained.

Three scenarios were considered and separate exercises have been carried out for these scenarios using this model. Before we discuss these scenarios, it must be recalled that this study considers only the operating costs of abatement. Capital cost of abatement is taken as a sunk cost (section 5). This implies that abatement equipment was exogenously given. Abatement efficiency of this equipment was, therefore, a function of design efficiency and vintage. This acts as an additional constraint on emission trading and thus results in under estimation of potential cost saving under emission trading *vis-à-vis* current regulatory system.

Present scenario examined the abatement efforts of BSP and associated costs under the current legislation, which are the command and control type (section 5). It can be seen in table 2 that currently, the total SPM abated by BSP is less than it would be in the base-case scenario, which requires application of a specified set of emission norms across all sources. Clearly, BSP is in violation with current legislation. Total abatement of SPM in BSP from the six sources considered in the study was 1,797.15 ton per day (column 2) at an average cost of abatement of Rs. 412 per ton. The distribution of total SPM abated by these sources is given in appendix 3. Marginal costs of SPM abatement varied from as low as Rs. 42.1 per kg to Rs. 2,486.4 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 at the margin per kg of SPM.

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

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

The base-case scenario represents a situation where legislated emission norms are met at all emission sources. Compliance with existing source emission norms at the sources considered in the study involved abatement of 1,849.9 ton of SPM per day at a total abatement cost of Rs. 285.62 million per year (table 2). The distribution of total SPM abated in the base-case scenario is given in appendix 3.

The *trading scenario*, using the model presented in section 4, obtained an allocation of abatement responsibility among various emission sources that simultaneously minimizes the total control costs and meets the target SPM concentration at all receptor locations. The most important observation that can be made on the basis of these results is that the *Sinter* plant, the highest abatement cost source, was 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 this by abating more than their legislated requirements. These facilities could take the additional SPM abatement responsibility by employing one or more of these measures: operating the abatement equipment at full potential/efficiency, improved maintenance of equipment for enhanced efficiency, and better maintenance of production facilities.

Column 3 of table 2 present 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 be 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, therefore, must be pointed out here. First, the cost savings reported above are an under estimate 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 the findings support the point that intra-plant emissions trading offer the opportunity to realize 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)[10] thus contributing to enhancement of social gains.

8. 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 contributing to improvement in ambient air quality in the studied geographical area. Furthermore, emission trading would provide an effective stimulus to the development and application of new emissions control technology. These appear to provide adequate justification for further experimentation and analysis of emissions trading schemes to control air pollution from large steel plants in India. Implementation of emission trading would, however, require a reform of the existing regulatory framework.

9. Issues for future research

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

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

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Appendix 1: Air quality model application

A simplified *Gaussian-Plume* model (CPCB, 1998), considering the point of concern at ground level (Z = 0), was applied. The equation used is:

$$X(x, y, 0, H) = Q/(\mathrm{II}\sigma_{\mathrm{y}}\sigma_z)\, exp\left(-y^2/2{\sigma_y}^2\right)\, exp\left(-H^2/2{\sigma_z}^2\right)$$

where:

$X(x, y, 0, H)$ = short-term concentration of pollutant at $(x, y, 0)$ in $\mu\mathrm{g/m}^3$ from a continuous point source with effective height, H;
x = down-wind distance (m);
y = lateral distance from plume centreline (m);
$H = h_s + h$; effective stack height (m);
h_s = physical stack height (m);
h = plume rise above the stack (m);
Q = source strength (μg/s);
u = wind speed at stack height (m/s);
σ_y = lateral dispersion parameter (m);
σ_z = vertical dispersion parameter (m).

The algorithm is useful for estimating air quality concentrations of relatively non-reactive pollutants. Calculations are performed on hourly meteorological data that the model requires, for example, wind direction, wind speed, temperature, stability class, and mixing height. Emission information required for the point sources are: source coordinates, emission rate, physical stack height, stack diameter, stack gas exit velocity, and stack gas temperature. Concentration estimates are made for each hourly period using the mean meteorological conditions approximate for each hour. The concentrations at a receptor for a period longer than an hour are determined by averaging the hourly concentrations over a period. The total concentration at a receptor is the sum of the concentrations estimated at the receptor from each source. The *Brooke-Heaven* dispersion parameters are used in the calculation.

Except for the stable layer aloft, which inhabits vertical dispersion, the atmosphere is treated as a single layer in the vertical that has the same rate of vertical dispersion throughout. Wind speed, measured at anemometer height, is extrapolated to the stack top using power law wind speed profiles with the exponent dependent upon stability. Plume rise is calculated using the method of Briggs. The ground level concentrations of suspended particulate matter for the 24-hourly averaging period were predicted at various receptors covering 20 × 20km area around the industry.

Appendix 2: 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	*Multicyclones* 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					
TPP	1	150	ESP	180	6
CPP	1	150	ESP	180	6
5 Blast furnace	3	150	Cyclone	50	8.2

Appendix 3: SPM abatement, total and marginal costs (present emission scenario)

Source	*Volumetric flow rate, (Nm^3/day)*	*SPM abated (tonnes per day)*	$\propto$	*Total cost of SPM abatement (Rs. lakh/year)*	*Marginal cost of SPM abatement (Rs./kg)*
1 Sinter plant (exhaust)	22,259,102.0	28.63	1.94	367.12	2,486.4
2 Sinter plant (discharge)	17,800,358.0	22.89	1.94	293.58	2,486.4
3 Kiln	17,046,771.2	99.87	1.54	154.42	238.5
4 SMS	25,870,176.0	87.47	1.83	856.11	1,786.7
5 TPP	32,719,660.8	973.61	1.24	329.62	42.1
6 CPP	30,833,912.0	527.63	1.38	492.37	128.6
7 Blast furnace	45,937,437.7	57.05	1.73	210.54	637.4
Total		1,797.15		2,703.77	

Appendix 4: SPM abatement, total and marginal costs (Base-case scenario)

Source	*Volumetric flow rate, (Nm^3/day)*	*Norms for SPM (mg/Nm^3)*	*SPM abated (tonnes per day)*	$\propto$	*Total cost of SPM abatement cost (Rs. lakh/year)*	*Marginal cost of SPM abatement (Rs./kg)*
1 Sinter plant (exhaust)	22,259,102.0	150	31.56	1.94	443.69	2,725.3
2 Sinter plant (discharge)	17,800,358.0	150	25.24	1.94	354.82	2,725.3
3 Kiln	17,046,771.2	150	98.55	1.54	151.28	236.8
4 SMS	25,870,176.0	400	84.72	1.83	807.75	1,740.4
5 TPP	32,719,660.8	150	972.04	1.24	328.96	42.1
6 CPP	30,833,912.0	150	581.28	1.38	562.67	133.4
7 Blast Furnace	45,937,437.7	150	56.50	1.73	207.04	632.9
Total			1,849.90		2,856.21	