CDE
December, 2002

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Working Paper No. 111

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Abstract

This paper develops a methodology for estimating potential cost savings from the use of market-based instruments (MBIs) when local emissions and abatement cost data are not available. The paper provides estimates of the cost savings for a 50% reduction of particulate emissions in India's five main industrial states, as well as estimates of the benefits from doing so. The estimates are developed by applying World Bank particulate intensity and abatement cost factors to sectoral output data. The estimated cost savings range from 26% to 169% and the benefits are many times greater than the costs even without the use of MBIs. The paper concludes by commenting on the relative difficulty of implementing reductions by market-based instruments and conventional command-and-control regulations.

JEL Classification: H23, Q25, Q28

Keywords: Water Pollution, Market-based instruments, Command and Control, Environmental Taxes.

Acknowledgement

This paper was written during my visit as Fulbright Fellow at the Massachusetts Institute of Technology during 2001-2002. I am thankful to the Center of Energy and Environmental Policy Research at MIT for its hospitality and for providing a stimulating research environment. The paper has benefited from comments/inputs by Amit Bando, Susmita Dasgupta, Denny Ellerman and Smita Siddhanti. All remaining errors and shortcomings are mine alone. Suneel Pandey helped with data gathering.

1. Introduction

In India environmental management is largely carried out at the state level. This is true for natural resources such as forests and land as well as for air, water quality and solid waste pollution. Therefore, the focus of efforts to improve environmental stewardship has to be at the state level.

This paper proposes and implements a methodology to evaluate the cost-effectiveness of market-based approaches to environmental management[1], and the benefits of reduced pollution. In particular, using state-level data from India, we quantify *potential* cost savings that would result from using a market-based instrument (MBI) such as an emissions tax compared to command and control (CAC) regulations, e.g., uniform abatement by all polluting sectors. These cost savings are juxtaposed against monetized benefits of improved environmental quality, particularly with respect to health effects of particulate air pollution. The purpose of this exercise is to: (i) highlight the cost-effectiveness of MBIs *vis-à-vis* CAC, and (ii) illustrate the potentially large benefits that better environmental management could achieve. Another application of this methodology could be to determine appropriate emission tax rates that would deliver a given level of emission reduction (and hence of reduction in ambient concentrations).

While there exist alternative approaches for abatement of pollution, in India as in several other countries the policy response to regulating pollution has been through command and control (CAC) strategies. These measures are essentially a set of “do’s” and “don’ts” that, *inter alia*, mandate ‘end-of-pipe’ emission/discharge standards and technology choices. Without going into the compulsions for adopting a CAC approach, there are a number of problems with the current regulatory regime from an economic point of view that are highlighted in this paper.

An alternate paradigm for pollution abatement is to use economic instruments (EIs) or market-based instruments (MBIs)[2]. These instruments use the market and

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1. A policy is cost-effective if it achieves a pre-specified goal at least-cost compared to alternative policies. For example, the goal could be to reduce ambient concentration of particulate matter at a particular location by *x* percent. This in turn could be translated into a target of reducing particulate emissions by *y* tons. If policy *A* achieved this reduction at a cost lower than policies *B* and *C*, it would be deemed cost-effective. It is important to note that this is not the same as the notion of *efficiency*.

2. A number of terms have been used to describe MBIs. Some of these are "economic incentives", "economic instruments", "economic approaches", "market-oriented approaches", "market-based incentives", "incentive mechanisms", and "incentive-based mechanisms". This paper treats them as equivalent.

price mechanism to encourage firms or households to adopt environmentally friendly practices. They comprise a wide range of instruments from traditional ones such as pollution taxes and tradable permits to input taxes, product charges and differential tax rates. *The common element among all MBIs is that they work through the market and affect the behavior of economic agents (such as firms and households) by changing the nature of incentives/disincentives these agents face*.

Market-based instruments (MBIs) should be an integral part of any strategy to strengthen environmental management at the state level. In contrast to traditional regulatory approaches such as CAC, MBIs (as stated above) work through economic incentives to induce environmentally friendly behavior. By allowing flexibility in attaining environmental goals (such as reduction in emissions) MBIs offer potential cost savings. Thus, a given environmental target can be attained at less cost to society than through other regulatory approaches. Alternately, the same amount of financial resources can potentially deliver greater environmental benefits with MBIs than under CAC (for further details see Gupta 2001, particularly Annex 1). Empirical evidence on this from simulation studies is discussed below. In addition, MBIs such as tradable emission permits if given away free (grandfathered) are assets for firms and create incentives for them to come forward and declare their emissions.

In the context of pollution control, the logic of using MBIs rests on two main premises. First, “end-of-pipe” waste treatment technologies that are often mandated under CAC are only one among several options for pollution abatement (other options could include process modification or use of cleaner inputs). MBIs, on the other hand, allow the firms flexibility in selecting among various options. Second, since costs of pollution abatement differ across firms, MBIs allow for the possibility of differential abatement across firms (with high-abatement-cost firms reducing emissions by a smaller amount compared to low-cost firms while still meeting overall emissions reduction targets as in CAC). In other words, MBIs result in lower total pollution abatement costs as compared to CAC because they allow a shift in abatement from high cost to low cost abaters. By contrast, CAC measures apply uniformly to all polluters such that the same environmental quality has to be achieved by polluters irrespective of their abatement cost structure[3].

3. Further, by creating an incentive for firms to abate more and save more (in terms of a smaller outlay on pollution taxes or through increased sale of tradable permits), MBIs can also spur technical change. On the other hand, under CAC there is no incentive to abate beyond the required level.

There exist a number of simulation studies that indicate the potential cost savings of using MBIs instead of CAC measures to achieve the same pollution target. These are summarized in Tables 1 and 2 for air and water pollution control, respectively[4]. In the tables, *potential* cost savings are shown as the ratio of costs under CAC (howsoever defined) to the lowest cost of meeting the same objective through an MBI. A ratio of 1.0 implies the CAC regime is cost-effective and there are no potential cost savings by using MBIs. It should be mentioned, however, these are simulation studies--they indicate cost savings that would take place if MBIs were to be used in place of CAC policies. Cost savings realized in practice would depend on the extent to which actual emissions trading programs (or other MBIs) approximated the least-cost solution. A recent study of the most extensive emissions trading program to date, namely, that of sulfur dioxide trading in the United States finds that an efficient, competitive allowance market has developed and the cost of permits (about $186 per ton of SO_2 removed) has been lower than anticipated (Ellerman et al. 2000).

It should also be noted that savings in costs under MBIs occur only if costs of pollution abatement differ significantly across firms. In the Indian context, given the wide variation in the nature of industrial activity in any given region, and in the vintage of plants, the quality of raw materials used, and the scale of operations, this assumption seems plausible, *if MBIs were to be implemented on a spatial basis*.

The paper also addresses implementation issues such as monitoring (of firms and emissions) and enforcement (of MBIs or CAC). Here we simply note that an

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4. In Table 1, pollutants are categorized along two dimensions--whether they are uniformly mixed and whether they are assimilative. 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. The situation is the opposite for *accumulative* pollutants. Most conventional pollutants, however (such as oxides of nitrogen and sulphur, total suspended particulates, and BOD), are assimilative in nature.

In the case of *uniformly mixed* pollutants, the ambient concentration of a pollutant depends on the total amount discharged, but not on the spatial distribution of these discharges among the various sources. Thus, a unit reduction in emission from any source within an airshed would have the same effect on ambient air quality. An example of this would be emissions of volatile organic compounds (VOCs) that uniformly contribute to concentration of ozone in an airshed. *Non-uniformly mixed* pollutants comprise air and water pollutants such as total suspended particulates, sulfur dioxide, and BOD. In these cases the *location* of the discharge matters--all sources do not affect ambient air/water quality in the same manner. In other words, damage costs from non-uniformly mixed pollutants are not uniform. In terms of analyzing various kinds of pollutants the easiest category is uniformly mixed assimilative pollutants.

appropriate legal and regulatory framework is a prerequisite for *both* MBIs and CAC. Further, the case has not been made yet that monitoring or enforcement requirements are greater under MBIs than under a *well functioning* CAC system for instance, one that requires regular monitoring of emissions (also see Gupta 2002). To begin with, there is a clear distinction between *monitoring*, i.e., ensuring that abatement activities/discharges of firms are in accordance with the laws and regulations and *enforcement*, that is, regulatory actions that make violators change their ways and also act as a deterrent (Russell 1992). With respect to monitoring, the requirements are the same under MBIs and a CAC regime that focuses on *continuing* compliance in contrast to *initial* compliance (see Russell et al. (1986) for details). As far as enforcement is concerned possible financial benefits under MBIs (from sale of emission permits or reduced pollution tax burden) could make enforcement easier than under CAC.

The following section outlines the steps to estimate the potential cost-effectiveness of MBIs *vis-a-vis* CAC. This is followed by an application of this methodology to abatement of particulate air pollution for selected states in India (section 3). Section 4 provides a brief look at the health benefits of reducing particulate pollution. Implementation challenges are addressed in section 5. The final section offers concluding thoughts and directions for further research.

2. Methodology

The steps in estimating the cost-effectiveness of MBIs are briefly described:

(i) The first step is to *estimate the pollution load* for each firm and industrial sector. Since actual information of this nature does not exist, it is estimated by using data on pollution intensities (effluent/emission per unit of output) from the World Bank Industrial Pollution Projection System (IPPS) database. Industrial output data by sector is collected from the official Annual Survey of Industry (ASI) in India. Note, pollution intensities are given by sector and thus assume that all firms *within* a sector are identical[5].

5. In effect, this implies that the variability in pollution intensities and MACs is greater *across* sectors than within. This is a reasonable assumption. It would, of course, be useful to have firm level data on pollution intensities and MACs (or at least have the data for each sector further broken down by size of firms, e.g., large, medium and small).

(ii) Next, *calculate the cumulative cost of pollution abatement* using estimates of marginal abatement cost (MAC) expressed in terms of US$ (1994 prices) per ton of pollutant reduced from the same World Bank IPPS database. These costs, however, are reported only at the sectoral level and are constant. In other words, for each sector there is only one cost figure implying that average and marginal cost of abatement are the same (total cost is a straight line through the origin). For particulates, MAC ranges from $2.43/ton for caustic soda to about $330/ton for leather. We arrange these in ascending order and convert them to 1987-88 rupees/ton (Table 7).

(iii) Finally, for a given level of total abatement, say 50 percent, *calculate the ratio of total abatement costs under CAC and MBIs*. For CAC, this entails dividing aggregate total cost by half, whereas for MBIs this requires calculating the cumulative cost of abatement upto the point where 50 percent of pollution is abated. The application described in the next section clarifies this further.

With respect to step (i) it should be noted that data on actual emissions by each source for a given spatial area would obviate the need to use standardized pollution intensities. In fact, a detailed and up to date emissions inventory by source is an important input into better environmental management at the state level[6]. Short of this, standardized pollution intensities could be developed, again at the state level, in place of the coefficients from IPPS used in the paper. A similar observation is in order for step (ii)—actual firm level data on marginal abatement costs would be ideal. In the absence of actual data on MACs, however, it would be useful to develop estimates based on Indian data rather than IPPS coefficients[7].

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6. A good example of this is the Toxics Release Inventory (TRI) in the United States. TRI is a publicly available database that contains information on toxic chemical releases into air, water and other media and other waste management activities reported annually by certain covered industry groups as well as federal facilities. See http://www.epa.gov/tri/ for details. Other countries that have similar emission inventories include Australia, Czech Republic, Mexico and the United Kingdom. See http://www.epa.gov/tri/programs/prtrs.htm for details. The characteristics of an ideal emissions inventory would be: (i) facility specific data; (ii) standardized data; (iii) chemical specific data; (iv) annual reporting; (v) public access to the data; (vi) mandatory reporting; (vii) limited trade secrecy; (viii) for each chemical, data on releases to air, water and land, and (ix) for each chemical, data on transfers of the chemical in waste.

7. This is not to suggest that IPPS data is not useful and/or appropriate. To the contrary, given the extent to which industrial processes/technologies are converging globally the IPPS does provide a useful benchmark. If Indian data on pollution intensities and MACs were available it would be useful to see how closely it corresponded to IPPS data. In the absence of such data there is no option but to

Broadly speaking, there are two approaches to estimating MACs. The first is a *bottom up (engineering) approach* also known as the programming approach. Here the cost of control technologies and the corresponding reduction in emissions (for a specific pollutant) are estimated for each firm. This approach reflects the ground reality that MACs are not smooth, twice differentiable convex curves as in textbooks. These idealized representations of MAC assume that small incremental increases in abatement are possible. In reality, however, abatement could be lumpy/indivisible generating a step-shaped or a piecewise linear MAC curve for each firm. For instance, for a given pollutant abatement technology I (scrubber) could cost X Rs. and reduce emissions by A tons, whereas technology II (process modification) could cost Y Rs. and reduce emissions by B tons, and so on. The point to note is that once a technology is picked (say technology I) it comes bundled with a (more or less) fixed amount of reduction in emissions. This also means that for each of these technologies (I, II, III, and so on) marginal cost = average cost, hence MAC for each firm is step-shaped MAC.

Secondly, under *econometric estimation of MAC (cost function approach)* an abatement cost function is econometrically estimated using cross-section plant level data. The assumption is that each plant minimizes the cost of producing output (*q*) subject to its production technology and a constraint on emissions/effluent. The latter is the regulatory standard facing the plant. The decision to be made at the plant level is to choose labor, capital and other inputs to minimize the cost of producing output *q* and achieving an emission/effluent discharge rate in time period *t*, subject to emissions and production constraints.

3. An application

As an illustration of the methodology outlined above we focus on 17 "highly polluting" industrial sectors as identified by the Central Pollution Control Board (CPCB) for implementation of pollution control programs (*http://cpcb.nic.in/17cat/17cat.html*). These sectors appear to be the focus of regulatory attention and are regularly highlighted in the annual reports of CPCB and on its website. Most state pollution control boards (SPCBs) also take their cue from CPCB in focusing on these sectors.

deploy a rapid assessment tool such as IPPS.

In an exercise of this nature where the focus is on the cost-effectiveness of alternative regulatory regimes, we limit the analysis to these sectors. These sectors are also major industrial sectors in terms of share of output and employment. They are: (1) aluminum smelting; (2) basic drugs and pharmaceuticals; (3) caustic soda; (4) cement; (5) copper smelting; (6) distillery; (7) dyes and dye intermediates; (8) fertilizer; (9) integrated iron and steel; (10) leather; (11) oil refineries; (12) pesticide (13) petrochemical; (14) paper and pulp; (15) sugar; (16) thermal power plants, and (17) zinc smelting.

Some of the categories (e.g., “leather”, “sugar”) are quite general and need to be described further in terms of specific processes that generate pollution. In other words, in order to use output data from ASI in conjunction with pollution coefficients from IPPS, it is necessary to translate the broad CPCB categories into specific sectors using industrial classification systems. This issue is discussed further below.

As stated earlier, emissions/effluent data is not gathered on a regular basis for most industries in India at the national or state level (only ambient air and water quality are monitored on a regular basis). SPCBs typically classify industries into broad categories based on their potential to pollute. For instance, Punjab PCB classifies units as "red" (highly polluting) or as "green" (marginally/moderately polluting). The objective is to subject units in the former category to more frequent monitoring and inspection than those in the latter. There is, however, no regular data collection of emission/effluent discharge for units in either category.

Thus, the *first step is to estimate the pollution load* for these 17 sectors by using the Industrial Pollution Projection System (IPPS) developed at the World Bank. IPPS exploits the fact that industrial pollution is highly affected by the scale of industrial activity and its sectoral composition. It operates through sector estimates of pollution intensity (usually defined as pollution load per unit of output or pollution load per unit of employment). Results from IPPS have been used in various countries where insufficient data on industrial pollution proved to be an impediment to setting up pollution control strategies and prioritization of activities, for example, Brazil, Latvia, Mexico and Vietnam. The IPPS methodology has also been used in published research such as Cole et al. (1998), Vukina et al. (1999) and Reinert and

Roland-Holst (2001a, 2001b)[8]. To our knowledge this paper is the first to apply this methodology to India.

Thus, sectoral estimates of pollution intensity from IPPS are applied to data on value of output for the polluting sectors identified by CPCB. This enables estimation of the pollution load at the state level for air pollutants such as NO_x, SO_2 and particulate matter, as well as water pollutants such as BOD and TSS. In doing so, one has to first map the broad categories defined by CPCB (e.g., leather, sugar) into specific industrial activities by ISIC codes (e.g., ISIC 3231--tanneries and leather finishing or ISIC 3118--sugar factories and refineries) that are typically used to measure output, value added, employment, etc[9]. Such a mapping is required to make the CPCB categories consistent with IPPS pollution intensities and marginal abatement costs (MACs) that are reported by ISIC.

Table 3 presents data on value of output for 15 CPCB polluting industries[10] and their corresponding ISIC codes for 5 states, namely, Maharashtra, Uttar Pradesh, Gujarat, Andhra Pradesh and Tamil Nadu[11]. According to CPCB, these states have the highest number of polluting firms (Table 4a). Hence, the paper focuses on these 5 states.

Value of output data for the 15 industries is from the Annual Survey of Industries (ASI) 1997-98. ASI is the principal source of industrial statistics in India[12]. Annex 1 shows the calculations used for arriving at the pollution load using IPPS and ASI data. IPPS pollution intensities for 3 air pollutants (SO_2, NO_2 and TSP) and for 2 water pollutants (BOD and TSS) are reported in Table 5, whereas estimated pollution loads for these pollutants for the 5 states are reported in Table 6.

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8. For additional examples of the application of IPPS see *http://www.worldbank.org/nipr/polmod.htm*.

9. ISIC—International Standard Industrial Classification is the classification approved by the United Nations in 1948 for adoption by various countries as a framework for rearranging national classifications to facilitate international comparability. It has undergone revisions from time to time and the latest version is ISIC Rev. 3 (1990) with ISIC Rev. 3.1 in draft form. IPPS uses ISIC Rev. 2 that dates to 1968. See *http://esa.un.org/unsd/cr/registry/* for details. The Indian equivalent of ISIC is the National Industrial Classification (NIC) and NIC 1998 is identical to ISIC Rev. 3. See *http://www.nic.in/stat/nic_98.htm*.

10. Two categories are excluded since IPPS does not have pollution intensities for thermal power plants and for petrochemicals ASI data is too disaggregated—over 50 compounds.

11. For some industries (such copper, aluminum and zinc smelting) the ISIC codes are the same since IPPS uses ISIC Rev.2 that does not have greater resolution.

12. See *http://www.nic.in/stat/stat_act_t3.htm* for details on ASI, the sampling frame and sampling design.

The next step is to use estimates of marginal abatement cost (MAC), that is, the amount of rupees required to reduce pollution load by an extra ton for each of the above pollutants for the 15 polluting sectors. These estimates again are from the World Bank IPPS database since this information is not yet available for India by sector and pollutant[13]. There have been some attempts to estimate MAC for water pollution for India though none for air pollution (see Goldar et al. 2001 for references). These studies, however, do not estimate MAC by sector and are of limited use for the current exercise.

As expected, for any given pollutant the MAC figures vary by sector and can thus be arranged in ascending order. This, in effect, gives us an overall MAC curve for each pollutant[14]. This curve is step-shaped and comprises a number of flat segments, each representing a sector (see Figure 1 for a stylized illustration of what such a curve would look like). Table 7 presents IPPS estimates of abatement costs for particulates (TSP) by sector, converted to 1987-88 rupees. As stated earlier, implicit here is the assumption that firms *within* a sector are similar in terms of MAC. While this may seem unrealistic, the important thing to keep in mind is that within a particular sector firms roughly produce the same kind of pollutants and use the same processes for abatement. To put it differently, it is likely that differences in MAC between firms *within* a sector are less as compared to differences in MAC *across* (very dissimilar) sectors.

In order to reduce pollution load of any given pollutant, a CAC regime would require uniform abatement across all sectors. For example, if the goal were to reduce the total particulate load by *x* percent, under a CAC regime *all* sectors emitting particulates would have to reduce their emissions by *x* percent (though their abatement costs differ greatly). On the other hand, with a MBI such as a tax on particulate emissions, low cost firms/sectors would do most of the abating (rather than paying the tax) whereas the high cost firms/sectors would pay the tax rather than abate.

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13. For details on estimation of MAC in IPPS see the paper by Hartman, Wheeler and Singh (1994) also available at the World Bank NIPR website.

14. The MAC curve plots the amount of *pollution abated* on the horizontal axis and the unit cost of abatement on the vertical axis. Alternately, the horizontal axis can depict the amount of *pollution generated* in which case the amount of abatement is read from right to left on the x-axis.

The above methodology is applied to particulate pollution (also known as total suspended particulate or TSP) for each of the 5 states. Here, we compute the total abatement costs under CAC for a 50 percent reduction in the pollution load and compare it with the cost that would result under an emissions tax (Table 8). The reason for focusing on particulates in the illustration is that they are considered to be the most serious pollutant from a human health perspective in India (Kandlikar and Ramachandran 2000).

In Table 8, for each of the 5 states the 15 polluting sectors are listed in *ascending order* by unit abatement cost (rupees per ton of TSP abated). Cumulative TSP load abated and cumulative abatement cost for each state are shown in columns 5 and 7, respectively. For example, for the state of Maharashtra, total TSP load from all sectors is 109,837 tons, whereas the cumulative abatement cost is 61.3 million rupees. Thus, under CAC if each sector were to reduce TSP load by 50 percent (uniform abatement), 54,918 tons of TSP would be abated at a cost of approximately 30.7 million rupees (half of 61.3 million).

On the other hand, with an MBI such as an emissions tax set *exactly* at Rs. 208.52 per ton of TSP, all caustic soda firms would abate completely whereas in the cement sector firms would be *indifferent* between paying the tax and abating. In any event, abatement would occur only in caustic soda and cement--for all other sectors, marginal abatement costs would be *higher* than the emissions tax, and they would then simply pay the tax.

Given the indifference of firms in the cement sector to abate/pay tax, they are apportioned between the two options such that the cost of 50 percent (cumulative) abatement can be read off the table (see cell with thick black border in final column of Table 8). Thus, a total of 54,918 tons of TSP would be abated for a total cost of 11.4 million rupees. Finally, the ratio of CAC (uniform abatement) to MBI (least cost) for a 50 percent reduction in TSP for Maharashtra is calculated at 2.69[15]. A similar exercise is carried for the other four states as well. The results are summarized in Table 9 where the ratio is greater than one for all states, implying thereby the need to take into account the variability in abatement costs across sectors.

15. That is, rupees [0.5(61,335,801)] divided by rupees 11,409,999. Also note that with an emissions tax set at Rs. 209/ton, the amount of abatement (65,951 tons) is more than 50 percent—it is in fact 60 percent.

It is important to note that given the step-shaped nature of the aggregate MAC curve for each state, *corner solutions* result. That is, firms in any given sector choose between full or zero abatement. For example, in Maharashtra with an emissions tax of Rs. 209 per ton the caustic soda and cement sectors would choose to reduce emissions to zero rather than pay the tax, whereas all other sectors would not abate at all[16]. Admittedly, this is a stylized description of the real world where there are a multitude of firms with varying MACs, such that the MAC curve for each sector has a smooth convex shape. Nevertheless, we believe this is still useful for illustrating the issue of CAC versus MBIs, albeit in an approximate manner. More satisfactory exercises have been carried out using detailed firm-level data for China. For instance, Dasgupta et al. (2001) and Cao et al. (1998) use similar methodology to estimate sectoral MACs for various water and/or air pollutants for 5 to 6 industrial sectors in China. They find substantial variation in MAC within sector between small, medium and large facilities and across sectors.

4. Estimating the environmental benefits of MBIs

The ultimate objective (or benefit) of regulating pollution whether through CAC or MBIs (such as emission taxes), is improved environmental quality. Specifically, the environmental benefits considered in this paper are health benefits of a reduction in particulate concentrations as a consequence of (MBI- or CAC-induced) reduction in TSP load. As stated earlier, the reason for focusing on air pollution from particulates is that they constitute a serious health problem. Some researchers have argued "particulate matter (PM) is the major cause of human mortality and morbidity from air pollution" (Kandlikar and Ramachandran 2000, p. 630). According to USEPA even in the United States (which on average has much lower particulate concentrations than India) there are 20,000-100,000 deaths annually due to particulate pollution.

In this context, it is important to note that the health impacts of the pollutants discussed above occur in terms of their *ambient concentrations* and not in terms of the pollution load. It is difficult to go from the latter to the former for non-uniformly dispersed pollutants without knowledge of their dispersion characteristics that vary across space and time. Nevertheless, as a first approximation we assume a *x*

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16. Also, as stated earlier if the tax rate were *exactly* Rs. 208.52 firms in the cement sector would be indifferent between abatement and paying the tax.

percent reduction in particulate load leads to an equivalent reduction in the ambient concentration of that pollutant[17]. In defense of this assumption it should be pointed out that the current regulatory regime in India does not make any connection what-so-ever between ambient environmental quality standards (such as NAAQS) and source specific discharge standards, and that this is a first step in that direction. Further, in India source-specific standards are typically specified in terms of maximum *rates* of discharge and/or maximum allowable concentration. Thus, there is no cap on *total emissions* from any particular source, let alone this cap being derived from an aggregate regional cap[18]. In effect then even a rough approximation that attempts to translate source-specific reductions into ambient concentrations, is a step in the right direction.

Based on the assumption in the preceding paragraph, we estimate the extent to which mortality and morbidity figures would be reduced if TSP (particulate) loads were reduced and what the corresponding monetary benefits would be[19]. Excess mortality and morbidity due to elevated concentrations of pollutants in air and water (i.e., air and water pollution) using Indian data has been estimated by Brandon and Hommann (1995) and Cropper et al. (1997). Here, we draw on the estimates of Brandon and Hommann (henceforth B-H) who examine air quality in 36 Indian cities. Of these, 10 cities are in the 5 states that are being considering in the paper, namely, Mumbai, Nagpur and Pune (all in Maharshtra), Ahmedabad and Surat (Gujarat), Hyderabad (Andhra Pradesh), Chennai (Tamil Nadu), and Agra, Kanpur and Varanasi (Uttar Pradesh). In particular, B-H estimate the reductions in mortality and morbidity that would occur if ambient particulate concentrations in these 36 cities were reduced to the WHO annual average standard. The mortality benefits are about 40,300 premature deaths avoided which translates into a monetary value of

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17. This approach is similar to what was used in the early days of regulation in countries such as the United States where State Implementation Plans (SIPs) were developed along these lines to achieve environmental goals.

18. A typical example of source specific discharge standards is shown in Table 10 that lists effluent/emission standards for thermal power plants in India. The last row in the table stipulates standards for air emissions. Note that the limits on particulate matter emissions are in terms of concentration and not the total amount of particulates a plant can emit.

19. Thus, a 50 percent reduction in particulate emissions would lead to a 50 percent reduction in ambient concentrations as well.

$170 - $1,615 million[20]. From this figure, corresponding figures for the 10 cities that are of interest to us are separated out and grouped by state (Table 11). Thus, we see that premature deaths annually due to air pollution range from 768 in Andhra Pradesh to 5,974 in Maharashtra with a corresponding large variation in monetary values as well.

Given the high levels of particulates in Indian cities it could be the case that even a 50 percent reduction in ambient concentrations (based on a 50% reduction in particulate emissions) may not be enough to achieve WHO standards. Thus, it could be argued that the B-H estimates of lives saved is not applicable. However, at the same time there are other urban agglomerations in these 5 states where health benefits of reduced particulate emissions would also accrue. At the same time, the spatial dispersion of the polluting sectors within a state relative to the distribution of population is not known[21]. Thus, the monetary values in Table 9 are a very rough approximation of the gains from reductions in particulate emissions discussed in section 3. Nevertheless, the values serve to fix in mind the rather large health benefits of reducing air pollution, which in turn is largely particulate pollution.

5. Issues of implementation with respect to MBIs

A discussion of MBIs in the Indian context is incomplete without reference to problems of monitoring and enforcement that were briefly mentioned in the introduction. In this context, the question to ask is “given the growing number of MBIs that are being used by countries around the world is India is so different that none of the country experiences can be replicated here?” And if so, what *are* these differences? In this context, note in particular the experience of China, Thailand, Malaysia, Indonesia, and other developing countries including the formerly planned economies of Europe. Many of these countries have (or had until recently), problems similar to those that are cited in the Indian context against the use of MBIs: imperfectly functioning markets, problems of monitoring and enforcing standards (due to a bloated and inefficient bureaucracy, shortage of resources, large number of

20. Three major cities account for 44% of total premature deaths—Delhi (19%), Calcutta (14%), and Mumbai (11%). For value of a statistical life (VSL), B-H use a range with the lower bound given by the human capital approach (discounted value of a ten-year wage stream) at $4,208/life, whereas the upper bound (calculated by scaling down US VSL estimates) comes to $40,017/life.

21. In effect within a state we have largely ignored the spatial dimension.

micro and small-scale firms), and so on. In our view, while these difficulties are real and cannot be ignored, it is also true that the Indian situation is amenable to the implementation of well-designed MBIs.

We agree that implementation of MBIs has certain prerequisites like well-functioning markets, information on the types of abatement technology available and its cost (O'Connor 1995). In addition, the collection of an emissions charge depends on a reasonably effective tax administration and monitoring of actual emissions. Tradable permit schemes require administrative machinery for issuing permits, tracking trades, and monitoring the actual emissions. Since the development of these capabilities is crucial for the effectiveness of the instruments, MBIs cannot be considered as a short cut to pollution control. In other words, MBIs have institutional requirements *just like regulatory measures*. The important point, however, is that these requirements are not greater for MBIs.

In this section we focus specifically on problems of monitoring and enforcement[22]. It is often claimed that since the effectiveness of MBIs depends crucially on the ability to successfully monitor discharges, till such time as the capability to monitor plant-level emissions/effluents is in place in India, it is not feasible to introduce MBIs. In response, it can be argued:

- Monitoring of discharges is required under a *properly functioning* command and control regime as well. The emphasis on the phrase "properly functioning" is deliberate: the current practice of merely confirming that pollution abatement equipment is installed and working is not enough[23]. This "checklist" approach to ensuring compliance does not provide much information about actual emissions/effluents. Therefore, monitoring of discharges is not a problem unique to MBIs.

In cases where direct monitoring of discharges is not possible (or is expensive), both theory and practice suggest several "second best" alternatives. To begin with, *there are a number of ways to indirectly estimate these discharges*. For instance:

22. For a general discussion of barriers to implementation of MBIs in India, see Gupta (2002).

23. In some cases, all that is required is that pollution abatement equipment is installed, not even whether it is operating properly. This is particularly true when courts are deciding whether to shut down polluting units.

- Data on inputs and/or output can be used to estimate emissions/effluents as long as the production function relationship between these variables is known (as we have done by applying IPPS). All that is required to implement these methods is detailed data on output in physical units or in monetary values. Of course, the more disaggregated the data, the more fine-tuned are the pollution coefficients, and the more accurate are the estimates of pollution load.
- The example of Sweden shows that it is possible to promote a system of *self-monitoring* among large firms. In this case standard emission rates were used for determining NOx charges for firms whenever emissions were not measurable. These rates were greater than the average actual emissions, and consequently encouraged the installation of measurement equipment by firms (OECD 1994, p. 59). This could be a feasible monitoring mechanism for large plants in India.

If it is not possible at all to estimate emissions/effluents (even indirectly), the following options are still available to regulators:

- They could use *indirect instruments* aimed at the outputs and inputs of the polluting industry or substitutes and complements to its outputs. For example, a tax on leather products would be an indirect method of addressing pollution from tanneries. These indirect instruments should be fine tuned to the extent possible, based on the pollution potential of different products/processes. For instance, a presumptive emissions tax on fuels should be differentiated by the emissions coefficients in different industries--thus, the cement industry which does not discharge the sulfur of its fuels, should ideally be refunded presumptive sulfur taxes on fuels (Eskeland and Jimenez, 1992).

Finally, if emissions are fully determined by the consumption of one good, then that good could be taxed (e.g., carbon taxes based on the carbon content of fuels). By the same token, substitutes to the polluting good could be subsidized (e.g., mass transit if private vehicles are a cause of urban air pollution), and complements to the polluting good could be taxed (such as parking space).

6. Conclusions

This exercise is a useful input into a framework for evaluation and selection of MBIs. By pulling together various strands of the analysis and using Indian data we are able to illustrate the environmental benefits and cost savings of MBIs. Despite the assumptions and approximations made in the process, this analysis can better inform policy-making for environmental management at the state level. In particular, we have demonstrated the use of existing databases (IPPS): (i) as a rapid assessment tool to arrive at source-specific/sectoral emission inventories, and (ii) to estimate the cost of reducing emissions through MBIs and CAC. In addition, we have shown how this approach can be used to demonstrate the cost-effectiveness of MBIs vis-à-vis CAC.

These estimates are then juxtaposed against monetary values of the health benefits of reducing particulate pollution. In the absence of spatial data on emissions and of dispersion characteristics a number of heroic assumptions have to be made. Nevertheless, since such an analysis has not been attempted before for India there is a novelty to the exercise. It can and should be repeated as and when better information and data becomes available. In particular, it would be useful to estimate firm level marginal abatement costs either through bottom up engineering estimates or through econometric estimation.

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Figure 1. Shape of marginal abatement cost curve with linear total cost

y axis is in rupees. Values of abatement costs (Rs./ton) for the 15 sectors in the IPPS database are arranged in *ascending* order on the vertical axis. The *x* axis is in terms of a specific pollutant (TSP in our illustration). It shows the amount of pollution generated by each sector, i.e., the width of the step.

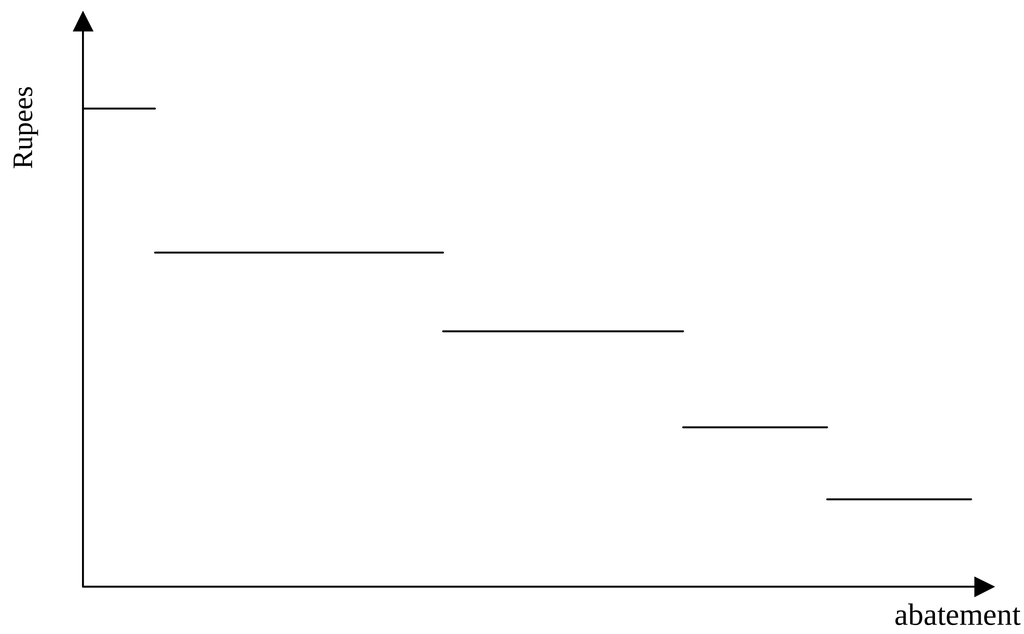

Table 1. Empirical studies of air pollution control

Study and Year	Pollutants Covered	Geographic Area	CAC benchmark	Assumed pollutant type	Ratio of CAC to least cost
Atkinson and Lewis (1974)	Particulates	St. Louis Metropolitan Area	SIP regulations	Nonuniformly mixed	6.00
Palmer, Mooz, Quinn, and Wolf (1980)	Chlorofluorocarbon emissions from nonaerosol applications	United States	Proposed emissions standards	Uniformly mixed accumulative	1.96
Roach, et al. (1981)	Sulfur dioxide	Four Corners in Utah, Colorado, Arizona and New Mexico	SIP regulations	Nonuniformly mixed	4.25
Hahn and Noll (1982)	Sulfates	Los Angeles	California emission standards	Nonuniformly mixed	1.07
Atkinson (1983)	Sulfur dioxide	Cleveland		Nonuniformly mixed	About 1.5
Harrison (1983)	Airport noise	United States	Mandatory retrofit	Uniformly mixed	1.72
Seskin, Anderson & Reid (1983)	Nitrogen dioxide	Chicago	Proposed RACT regulations	Nonuniformly mixed	14.40
Maloney and Yandle (1984)	Hydrocarbons	All domestic Du Pont plants	Uniform percentage reduction	Uniformly mixed	4.15
McGartland (1984)	Particulate	Baltimore	SIP regulations	Nonuniformly mixed	4.18
Spofford (1984)	Sulfur dioxide	Lower Delaware Valley	Uniform percentage reduction	Nonuniformly mixed	1.78

continued

Table 1 continued. Empirical studies of air pollution control

Study and Year	Pollutants Covered	Geographic Area	CAC benchmark	Assumed pollutant type	Ratio of CAC to least cost
Spofford (1984)	Particulates	Lower Delaware Valley	Uniform percentage reduction	Nonuniformly mixed	22.00
Krupnick (1986)	Nitrogen dioxide	Baltimore	Proposed RACT regulations	Nonuniformly mixed	5.9
Welsch (1988)	Sulfur dioxide	United Kingdom		Nonuniformly mixed	1.4-2.5
Oates, et al. (1989)	TSP	Baltimore	Equal proportional treatment	Nonuniformly mixed	4.0 at 90 $\mu g/m^3$
SCAQMD (1992)	Reactive Organic Gases/Nitrogen dioxide	Southern California	Best available control technology	Nonuniformly mixed	1.5 in 1994

TSP = Total Suspended Particulates
SCAQMD = South Coast Air Quality Management District
SIP = State Implementation Plan (strategy by a state in the US to meet federal environmental standards)
RACT = Reasonably Available Control Technologies, a set of standards imposed on existing sources in non attainment areas

Source: Tietenberg (1985), USEPA (1992) and World Bank (1992)

Table 2. Empirical studies of water pollution control

Study and Year	Pollutants Covered	Geographic Area	CAC benchmark	DO target (mg/litre)	Ratio of CAC cost to least cost
Johnson (1967)	Biochemical oxygen demand	Delaware Estuary - 86-mile reach	Equal proportional treatment	2.0 3.0 4.0	3.13 1.62 1.43
O'Neil (1980)	Biochemical oxygen demand	20-mile segment of Lower Fox River in Wisconsin	Equal proportional treatment	2.0 4.0 6.2 7.9	2.29 1.71 1.45 1.38
Eheart, Brill, and Lyon (1983)	Biochemical oxygen demand	Willamette River in Oregon	Equal proportional treatment	4.8 7.5	1.12 1.19
		Delaware Estuary in Penn., Delaware, and New Jersey	Equal proportional treatment	3.0 3.6	3.00 2.92
		Upper Hudson River in New York	Equal proportional treatment	5.1 5.9	1.54 1.62
		Mohawk River in New York	Equal proportional treatment	6.8	1.22
Opaluch and Kashmanian (1985)	Heavy metals	Rhode Island Jewelry Industry	Technology-based standards		1.8

DO = Dissolved oxygen--higher DO targets indicate higher water quality

Source: Tietenberg (1985) and USEPA (1992)

Table 3. Value of output 1997-98 (rupees thousand at 1987-88 prices)

CPCB category	ISIC Code	Four digit ISIC description	Maharashtra	Gujarat	Andhra Pradesh	Tamil Nadu	Uttar Pradesh
Aluminium smelter	3720	Nonferrous metals	155462	0	0	0	0
Basic drugs and pharmaceuticals	3522	Drugs and medicines	4790457	971344	823978	2061920	287225
Caustic soda	3511	Industrial chemicals except fertilizer	373848	854805	574824	599646	243317
Cement	3692	Cement, lime, and plaster	3017815	4400902	3586549	5599154	193913
Copper smelter	3720	Nonferrous metals	58356	0	53313	0	0
Distilleries	3131	Distilled spirits	893477	0	276006	1956470	895107
Dyes and dye intermediates	3211	Spinning, weaving and finishing textiles	2231267	6497946	0	57092	1934
Fertiliser	3512	Fertilizers and pesticides	8244055	5827671	2766260	1775221	13605411
Integrated iron and steel	3710	Iron and steel	3665310	1208602	3775821	462068	517631
Leather	3231	Tanneries and leather finishing	17234	41141	3083	4054542	1146688
Oil refineries	3530	Petroleum refineries	28060249	5756601	2209561	3714842	7964682
Pesticides	3512	Fertilizers and pesticides	4011664	6133013	1924831	796369	140420
Pulp and paper	3411	Pulp, paper, and paperboard	706653	832058	1401817	4225917	1510495
Sugar	3118	Sugar factories and refineries	15913434	4424972	4541418	6081343	21644261
Zinc smelter	3720	Nonferrous metals	76604	0	744848	0	6195

Source: Annual Survey of Industries, Central Statistical Organisation, New Delhi

Table 4a. Statewise distribution of polluting industries

Andhra Pradesh	173
Arunachal Pradesh	0
Assam	15
Bihar	62
Goa	6
Gujarat	177
Haryana	43
Himachal Pradesh	9
Jammu and Kashmir	8
Karnataka	85
Kerala	28
Madhya Pradesh	78
Maharashtra	335
Manipur	0
Meghalaya	1
Mizoram	0
Nagaland	0
Orissa	23
Punjab	45
Rajasthan	49
Sikkim	1
Tamil Nadu	119
Tripura	0
Uttar Pradesh	224
West Bengal	58
Union Territories (UT):	
Andman & Nicobar	0
Chandigarh	1
Daman & Diu	0
Dadra & Nagar Haveli	0
Delhi	5
Lakshadweep	0
Pondichery	6
Total	1551

Table 4b. Distribution of industries by category

Aluminium smelter	7
Caustic soda	25
Cement	116
Copper smelter	2
Distilleries	177
Dyes and dye intermediates	64
Fertiliser	110
Integrated iron and steel	8
Leather	70
Pesticide	71
Petrochemicals	49
Basic drugs and pharmaceuticals	251
Pulp and paper	96
Oil refineries	12
Sugar	392
Thermal power plants	97
Zinc smelter	4
Total	1551

Table 5. IPPS pollution intensities for air and water pollutants

CPCB category	ISIC	Four Digit ISIC Description	kilograms/thousand rupees (1987-88 rupees) SO2	NO2	TSP	BOD	TSS
Aluminium smelter	3720	Nonferrous metals	1.352	0.044	0.114	0.104	1.498
Basic drugs and pharmaceuticals	3522	Drugs and medicines	0.064	0.027	0.012	0.002	0.536
Caustic soda	3511	Industrial chemicals except fertilizer	0.408	0.303	0.066	0.140	0.216
Cement	3692	Cement, lime, and plaster	4.502	2.090	2.177	0.000	0.091
Copper smelter	3720	Nonferrous metals	1.352	0.044	0.114	0.104	1.498
Distilleries	3131	Distilled spirits	0.136	0.047	0.011	0.191	0.343
Dyes and dye intermediates	3211	Spinning, weaving and finishing textiles	0.085	0.117	0.015	0.003	0.005
Fertiliser	3512	Fertilizers and pesticides	0.039	0.037	0.011	0.002	0.305
Integrated iron and steel	3710	Iron and steel	0.625	0.272	0.145	0.000	6.812
Leather	3231	Tanneries and leather finishing	0.045	0.012	0.005	0.021	0.040
Oil refineries	3530	Petroleum refineries	0.443	0.255	0.039	0.006	0.028
Pesticides	3512	Fertilizers and pesticides	0.039	0.037	0.011	0.002	0.305
Pulp and paper	3411	Pulp, paper, and paperboard	0.895	0.467	0.176	0.481	1.634
Sugar	3118	Sugar factories and refineries	0.225	0.216	0.149	0.075	0.107
Zinc smelter	3720	Non ferrous metals	1.352	0.044	0.114	0.104	1.498

Table 6. Estimated pollution load by state, 1997-98 (kilograms)

Maharashtra

CPCB category	ISIC	Four digit ISIC description	SO2	NO2	TSP	BOD	TSS
Aluminium smelter	3720	Nonferrous metals	210179	6847	17654	16115	232938
Basic drugs and pharmaceuticals	3522	Drugs and medicines	305844	129879	57817	10238	2566530
Caustic soda	3511	Industrial chemicals except fertilizer	152442	113233	24496	52168	80636
Cement	3692	Cement, lime, and plaster	13585960	6308084	6570643	125	273178
Copper smelter	3720	Nonferrous metals	78894	2570	6627	6049	87438
Distilleries	3131	Distilled spirits	121495	42228	10158	170380	306230
Dyes and dye intermediates	3211	Spinning, weaving and finishing textiles	189054	260866	33799	7664	11901
Fertiliser	3512	Fertilizers and pesticides	318974	307150	88540	12944	2518507
Integrated iron and steel	3710	Iron and steel	2290984	995149	530849	1695	24969495
Leather	3231	Tanneries and leather finishing	783	207	95	366	692
Oil refineries	3530	Petroleum refineries	12431460	7151231	1096489	155374	779784
Pesticides	3512	Fertilizers and pesticides	155217	149463	43085	6298	1225538
Pulp and paper	3411	Pulp, paper, and paperboard	632486	330000	124297	339947	1154589
Sugar	3118	Sugar factories and refineries	3578487	3435415	2370442	1186184	1700711
Zinc smelter	3720	Nonferrous metals	103565	3374	8699	7940	114780

Gujarat

CPCB category	ISIC	Four digit ISIC description	SO2	NO2	TSP	BOD	TSS
Aluminium smelter	3720	Nonferrous metals	0	0	0	0	0
Basic drugs and pharmaceuticals	3522	Drugs and medicines	62015	26335	11723	2076	520406
Caustic soda	3511	Industrial chemicals except fertilizer	348559	258907	56010	119283	184375
Cement	3692	Cement, lime, and plaster	19812509	9199127	9582020	182	398378
Copper smelter	3720	Nonferrous metals	0	0	0	0	0
Distilleries	3131	Distilled spirits	0	0	0	0	0
Dyes and dye intermediates	3211	Spinning, weaving and finishing textiles	550567	759700	98429	22318	34659
Fertiliser	3512	Fertilizers and pesticides	225481	217122	62588	9150	1780317
Integrated iron and steel	3710	Iron and steel	755431	328141	175042	559	8233459
Leather	3231	Tanneries and leather finishing	1870	494	226	874	1651
Oil refineries	3530	Petroleum refineries	2550332	1467085	224946	31875	159974
Pesticides	3512	Fertilizers and pesticides	237295	228498	65868	9629	1873597
Pulp and paper	3411	Pulp, paper, and paperboard	744730	388564	146355	400276	1359488
Sugar	3118	Sugar factories and refineries	995053	955269	659137	329836	472909
Zinc smelter	3720	Nonferrous metals	0	0	0	0	0

Table 6 continued

Andhra Pradesh

CPCB category	ISIC	Four digit ISIC description	SO2	NO2	TSP	BOD	TSS
Aluminium smelter	3720	Nonferrous metals	0	0	0	0	0
Basic drugs and pharmaceuticals	3522	Drugs and medicines	52606	22340	9945	1761	441454
Caustic soda	3511	Industrial chemicals except fertilizer	234393	174105	37665	80214	123985
Cement	3692	Cement, lime, and plaster	16146355	7496898	7808940	148	324661
Copper smelter	3720	Nonferrous metals	72077	2348	6054	5526	79883
Distilleries	3131	Distilled spirits	37531	13045	3138	52633	94598
Dyes and dye intermediates	3211	Spinning, weaving and finishing textile	0	0	0	0	0
Fertiliser	3512	Fertilizers and pesticides	107031	103063	29709	4343	845075
Integrated iron and steel	3710	Iron and steel	2360059	1025153	546854	1746	25722340
Leather	3231	Tanneries and leather finishing	140	37	17	66	124
Oil refineries	3530	Petroleum refineries	978896	563113	86341	12235	61403
Pesticides	3512	Fertilizers and pesticides	74474	71714	20672	3022	588024
Pulp and paper	3411	Pulp, paper, and paperboard	1254690	654636	246573	674367	2290408
Sugar	3118	Sugar factories and refineries	1021238	980408	676483	338516	485353
Zinc smelter	3720	Nonferrous metals	1007005	32806	84582	77208	1116052

Tamil Nadu

CPCB category	ISIC	Four digit ISIC description	SO2	NO2	TSP	BOD	TSS
Aluminium smelter	3720	Nonferrous metals	0	0	0	0	0
Basic drugs and pharmaceuticals	3522	Drugs and medicines	131642	55903	24886	4407	1104692
Caustic soda	3511	Industrial chemicals except fertilizer	244514	181624	39291	83677	129339
Cement	3692	Cement, lime, and plaster	25206942	11703811	12190955	231	506846
Copper smelter	3720	Nonferrous metals	0	0	0	0	0
Distilleries	3131	Distilled spirits	266040	92467	22244	373086	670559
Dyes and dye intermediates	3211	Spinning, weaving and finishing textile	4837	6675	865	196	305
Fertiliser	3512	Fertilizers and pesticides	68686	66140	19066	2787	542319
Integrated iron and steel	3710	Iron and steel	288813	125454	66922	214	3147782
Leather	3231	Tanneries and leather finishing	184251	48651	22269	86153	162693
Oil refineries	3530	Petroleum refineries	1645777	946737	145162	20570	103234
Pesticides	3512	Fertilizers and pesticides	30813	29670	8553	1250	243286
Pulp and paper	3411	Pulp, paper, and paperboard	3782389	1973465	743320	2032948	6904665
Sugar	3118	Sugar factories and refineries	1367525	1312849	905868	453302	649929
Zinc smelter	3720	Nonferrous metals	0	0	0	0	0

Table 6 continued **Uttar Pradesh**

CPCB category	ISIC	Four digit ISIC description	SO2	NO2	TSP	BOD	TSS
Aluminium smelter	3720	Nonferrous metals	0	0	0	0	0
Basic drugs and pharmaceuticals	3522	Drugs and medicines	18338	7787	3467	614	153883
Caustic soda	3511	Industrial chemicals except fertilizer	99216	73697	15943	33954	52482
Cement	3692	Cement, lime, and plaster	872981	405333	422204	8	17553
Copper smelter	3720	Nonferrous metals	0	0	0	0	0
Distilleries	3131	Distilled spirits	121716	42305	10177	170691	306788
Dyes and dye intermediates	3211	Spinning, weaving and finishing textiles	164	226	29	7	10
Fertiliser	3512	Fertilizers and pesticides	526413	506898	146120	21361	4156368
Integrated iron and steel	3710	Iron and steel	323543	140539	74969	239	3526298
Leather	3231	Tanneries and leather finishing	52109	13759	6298	24365	46012
Oil refineries	3530	Petroleum refineries	3528573	2029821	311230	44102	221335
Pesticides	3512	Fertilizers and pesticides	5433	5232	1508	220	42897
Pulp and paper	3411	Pulp, paper, and paperboard	1351962	705388	265689	726649	2467976
Sugar	3118	Sugar factories and refineries	4867191	4672594	3224097	1613359	2313180
Zinc smelter	3720	Nonferrous metals	8375	273	703	642	9282

Table 7. Abatement costs for particulates (TSP)

CPCB category	ISIC code	(1987-88 Rupees/ton)
Caustic soda	3511	38.90
Cement	3692	208.52
Oil refineries	3530	376.85
Pulp and paper	3411	653.32
Sugar	3118	922.04
Fertiliser	3512	1106.67
Pesticides	3512	1106.67
Integrated iron and steel	3710	2690.90
Distilleries	3131	2828.73
Aluminium smelter	3720	3197.99
Copper smelter	3720	3197.99
Zinc smelter	3720	3197.99
Dyes and dye intermediates	3211	3909.73
Basic drugs and pharmaceuticals	3522	4177.00
Leather	3231	5286.25

Table 8. Cumulative abatement cost for particulates (TSP)

Maharashtra

CPCB category	**ISIC**	**Abatement cost for TSP (Rupees/ton)**	**TSP load (kilograms)**	**Cumulative TSP load (tons)**	**Total abatement cost (Rupees)**	**Cumulative abatement cost (Rupees)**
Caustic soda	3511	38.90	24496	245	9528	9528
Cement (upto 50% cumulative abatement)	3692	208.52	5467350	**54918**	11400471	**11409999**
Cement (beyond 50% cumulative abatement)	3692	208.52	1103293	65951	2300577	13710576
Oil refineries	3530	376.85	1096489	76916	4132137	17842714
Pulp and paper	3411	653.32	124297	78159	812054	18654767
Sugar	3118	922.04	2370442	101864	21856315	40511082
Fertiliser	3512	1106.67	88540	102749	979843	41490925
Pesticides	3512	1106.67	43085	103180	476804	41967730
Integrated iron and steel	3710	2690.90	530849	108488	14284595	56252325
Distilleries	3131	2828.73	10158	108590	287354	56539679
Aluminium smelter	3720	3197.99	17654	108767	564560	57104239
Copper smelter	3720	3197.99	6627	108833	211918	57316156
Zinc smelter	3720	3197.99	8699	108920	278186	57594343
Dyes and dye intermediates	3211	3909.73	33799	109258	1321437	58915779
Basic drugs and pharmaceuticals	3522	4177.00	57817	109836	2415017	61330797
Leather	3231	5286.25	95	109837	5004	61335801
TOTAL			**10983688**		**61335801**	
Ratio of CAC (uniform abatement) to least cost for 50% reduction in TSP			**2.69**			

Gujarat

CPCB category	**ISIC**	**Abatement cost for TSP (Rupees/ton)**	**TSP load (kilograms)**	**Cumulative TSP load (tons)**	**Total abatement cost (Rupees)**	**Cumulative abatement cost (Rupees)**
Caustic soda	3511	38.90	56010	560.1	21785	21785
Cement (upto 50% cumulative abatement)	3692	208.52	5485165	**55411.7**	11437619	**11459405**
Cement (beyond 50% cumulative abatement)	3692	208.52	4096855	96380.3	8542727	20002132
Oil refineries	3530	376.85	224946	98629.8	847714	20849846
Pulp and paper	3411	653.32	146355	100093.3	956165	21806010
Sugar	3118	922.04	659137	106684.7	6077481	27883491
Fertiliser	3512	1106.67	62588	107310.6	692645	28576136
Pesticides	3512	1106.67	65868	107969.2	728936	29305072
Integrated iron and steel	3710	2690.90	175042	109719.7	4710213	34015285
Distilleries	3131	2828.73	0	109719.7	0	34015285
Aluminium smelter	3720	3197.99	0	109719.7	0	34015285
Copper smelter	3720	3197.99	0	109719.7	0	34015285
Zinc smelter	3720	3197.99	0	109719.7	0	34015285
Dyes and dye intermediates	3211	3909.73	98429	110704.0	3848318	37863603
Basic drugs and pharmaceuticals	3522	4177.00	11723	110821.2	489684	38353287
Leather	3231	5286.25	226	110823.5	11945	38365232
TOTAL			**11082346**		**38365232**	
Ratio of CAC (uniform abatement) to least cost for 50% reduction in TSP			**1.67**			

Andhra Pradesh

CPCB category	ISIC	Abatement cost for TSP (Rupees/ton)	TSP load (kilograms)	Cumulative TSP load (tons)	Total abatement cost (Rupees)	Cumulative abatement cost (Rupees)
Caustic soda	3511	38.90	37665	376.6	14650	14650
Cement (upto 50% cumulative abatement)	3692	208.52	4740825	**47784.9**	9885528	**9900178**
Cement (beyond 50% cumulative abatement)	3692	208.52	3068115	78466.0	6397607	16297785
Oil refineries	3530	376.85	86341	79329.5	325379	16623164
Pulp and paper	3411	653.32	246573	81795.2	1610906	18234069
Sugar	3118	922.04	676483	88560.0	6237413	24471482
Fertiliser	3512	1106.67	29709	88857.1	328783	24800265
Pesticides	3512	1106.67	20672	89063.8	228775	25029040
Integrated iron and steel	3710	2690.90	546854	94532.4	14715284	39744324
Distilleries	3131	2828.73	3138	94563.8	88767	39833091
Aluminium smelter	3720	3197.99	0	94563.8	0	39833091
Copper smelter	3720	3197.99	6054	94624.3	193607	40026698
Zinc smelter	3720	3197.99	84582	95470.1	2704912	42731610
Dyes and dye intermediates	3211	3909.73	0	95470.1	0	42731610
Basic drugs and pharmaceuticals	3522	4177.00	9945	95569.6	415393	43147003
Leather	3231	5286.25	17	95569.7	895	43147898
TOTAL			**9556973**		**43147898**	
Ratio of CAC (uniform abatement) to least cost for 50% reduction in TSP			**2.18**			

Tamil Nadu

CPCB category	ISIC	Abatement cost for TSP (Rupees/ton)	TSP load (kilograms)	Cumulative TSP load (tons)	Total abatement cost (Rupees)	Cumulative abatement cost (Rupees)
Caustic soda	3511	38.90	39291	392.9	15282	15282
Cement (upto 50% cumulative abatement)	3692	208.52	7055409	**70947.0**	14711879	**14727161**
Cement (beyond 50% cumulative abatement)	3692	208.52	5135546	122302.5	10708597	25435758
Oil refineries	3530	376.85	145162	123754.1	547046	25982803
Pulp and paper	3411	653.32	743320	131187.3	4856237	30839041
Sugar	3118	922.04	905868	140246.0	8352424	39191465
Fertiliser	3512	1106.67	19066	140436.6	210993	39402458
Pesticides	3512	1106.67	8553	140522.1	94652	39497110
Integrated iron and steel	3710	2690.90	66922	141191.4	1800789	41297899
Distilleries	3131	2828.73	22244	141413.8	629227	41927126
Aluminium smelter	3720	3197.99	0	141413.8	0	41927126
Copper smelter	3720	3197.99	0	141413.8	0	41927126
Zinc smelter	3720	3197.99	0	141413.8	0	41927126
Dyes and dye intermediates	3211	3909.73	865	141422.5	33812	41960938
Basic drugs and pharmaceuticals	3522	4177.00	24886	141671.3	1039478	43000416
Leather	3231	5286.25	22269	141894.0	1177196	44177612
TOTAL			**14189400**		**44177612**	
Ratio of CAC (uniform abatement) to least cost for 50% reduction in TSP			**1.50**			

Table 8 (continued) **Uttar Pradesh**

CPCB category	ISIC	Abatement cost for TSP (Rupees/ton)	TSP load (kilograms)	Cumulative TSP load (tons)	Total abatement cost (Rupees)	Cumulative abatement cost (Rupees)
Caustic soda	3511	38.90	15943	159.4	6201	6201
Cement	3692	208.52	422204	4381.5	880377	886578
Oil refineries	3530	376.85	311230	7493.8	1172875	2059452
Pulp and paper	3411	653.32	265689	10150.7	1735794	3795247
Sugar (upto 50% cumulative abatement)	3118	922.04	1226150	**22412.2**	11305538	**15100785**
Sugar (beyond 50% cumulative abatement)	3118	922.04	1997947	42391.6	18421784	33522569
Fertiliser	3512	1106.67	146120	43852.8	1617064	35139633
Pesticides	3512	1106.67	1508	43867.9	16690	35156323
Integrated iron and steel	3710	2690.90	74969	44617.6	2017331	37173654
Distilleries	3131	2828.73	10177	44719.4	287878	37461532
Aluminium smelter	3720	3197.99	0	44719.4	0	37461532
Copper smelter	3720	3197.99	0	44719.4	0	37461532
Zinc smelter	3720	3197.99	703	44726.4	22496	37484029
Dyes and dye intermediates	3211	3909.73	29	44726.7	1145	37485174
Basic drugs and pharmaceuticals	3522	4177.00	3467	44761.4	144799	37629973
Leather	3231	5286.25	6298	44824.4	332930	37962902
TOTAL			**4482435**		**37962902**	
Ratio of CAC (uniform abatement) to least cost for 50% reduction in TSP			**1.26**			

Table 9. Ratio of CAC to least cost abatement for 50% reduction in TSP load

Maharashtra	2.69
Gujarat	1.67
Andhra Pradesh	2.18
Tamil Nadu	1.50
Uttar Pradesh	1.26

Table 10. Environmental standards for thermal power plants in India

Process	**Environmental Parameter**	**Concentration not to exceed in mg/litre (except for pH)**
Condenser cooling waters (once through cooling system)	pH	6.5 - 8.5
	Temperature	Not more than 5°C higher than intake water temperature
	Free available chlorine	0.5
Boiler blowdowns	Suspended solids	100
	Oil and grease	20
	Copper (total)	1.0
	Iron (total)	1.0
Cooling tower blowdowns	Free available chlorine	0.5
	Zinc	1.0
	Chromium (total)	0.2
	Phosphate	5.0
	Other corrosion inhibiting material	Limit to be established on case by case basis by CPCB for Union Territories and SPCBs for states
Ash pond effluent	PH	6.5-8.5
	Suspended solids	100
	Oil and grease	20
Air emissions	Particulate matter:	
	(i) ≥ 210 MW capacity	150 mg/m^3
	(ii) < 210 MW capacity	350 mg/m^3
	Sulphur dioxide:	Stack height in metres
	(i) 500 MW capacity	275
	(ii) 200/210 to 500 MW capacity	220
	(iii) < 200/210 MW capacity	$H=14(Q)^{0.3}$ (Q - emission rate of SO_2 in kg/hour)

Table 11. Estimates of annual health incidence in selected Indian cities due to ambient air pollution levels exceeding WHO guidelines

	Premature deaths		
	Number	**Value ($)--lower bound**	**Value ($)--upper bound**
Mumbai	4,477	18,839,216	179,156,109
Nagpur	506	2,129,248	20,248,602
Pune	991	4,170,128	39,656,847
Maharashtra	**5,974**	**25,138,592**	**239,061,558**
Ahmedabad	2,979	12,535,632	119,210,643
Surat	1,488	6,261,504	59,545,296
Gujarat	**4,467**	**18,797,136**	**178,755,939**
Hyderabad	768	3,231,744	30,733,056
Andhra Pradesh	**768**	**3,231,744**	**30,733,056**
Chennai	863	3,631,504	34,534,671
Tamil Nadu	**863**	**3,631,504**	**34,534,671**
Agra	1,569	6,602,352	62,786,673
Kanpur	1,894	7,969,952	75,792,198
Varanasi	1,851	7,789,008	74,071,467
Uttar Pradesh	**5,314**	**22,361,312**	**212,650,338**
All 36 cities	**40,351**	**169,797,008**	**1,614,725,967**

Source: Brandon and Hommann (1995)

Annex 1. Applying appropriate conversion factors to IPPS and ASI data to arrive at pollution load and abatement costs

In the IPPS:

1. Pollution intensities (emission factors) are in kilograms per US$ million at 1987 prices.
2. Abatement cost coefficients (cost per ton abated) are in US$ per ton abated at 1994 prices.

The Annual Survey of Industry (ASI) output data is in thousand rupees at current (1997-98) prices. The Indian financial year (FY) runs from April 1 to 31 March. All data are reported by FY. We assume calendar year t = $FY_{t - t+1}$, e.g., calendar 1987 = FY 1987-88.

The following steps are used in calculating pollution loads:

1. Convert IPPS pollution intensities to Indian rupees (INR). In 1987-88, INR 12.966 = US$ 1. (Source: Economic Survey 2000-2001 Table 6.5 http://www.indiabudget.nic.in/es2000-01/). So, dividing pollution intensity by 12,966 gives us kilograms (of SO2, NO2, etc.) per thousand INR in 1987-88.

2. Deflate ASI output data to 1987-88 prices. We use the official wholesale price index (WPI) for the manufacturing sub group. A problem that arises is that the base year for WPI was changed effective April 1, 2000 from 1981-82 = 100 to 1993-94 = 100. (See http://eaindustry.nic.in/pib.htm for details). A linking factor of 2.43 is used to convert WPI for 1997-98 to 1987-88 because manufacturing group WPI (average of weeks) under old series in 1993-94 was 243. See Table 5.1 of Economic Survey 2000-2001 op. cit. Thus,

   1987-88 manufactured products WPI (1981-82 base) = 139

   1997-98 manufactured products WPI (1993-94 base) = 128

   So we use [139 / (128 ∗ 2.43)] = **0.44688878** as the deflator.

3. Convert IPPS abatement cost coefficients to INR at 1987-88 prices.

(i) First, multiply IPPS figure by 31.399 (in 1994-95, INR 31.399 = US$ 1, Economic Survey Table 6.5, op. cit.) to arrive at rupees per ton abated in 1994-95 prices.

(ii) Then deflate using steps similar to (2) above to arrive at 1987-88 prices. Thus,

1987-88 WPI manufacturing (1981-82 base) = 139

1994-95 WPI manufacturing (1993-94 base) = 112

So we use [139 / (112 ∗ 2.43)] = **0.5107289** as the deflator.

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