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Economies of Scale in Water Pollution Abatement: A Case of Small-Scale Factories in an Industrial Estate in India

Smita Misra*

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Centre for Development Economics
Delhi School of Economics
Delhi 110 007 INDIA
Tel : 7257005, 7256533-35
Fax : 011-7257159
E-mail : office@cdedse.ernet.in

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ABSTRACT

This paper provides empirical evidence of economies of scale in water pollution abatement activity at Nandesari Industrial Estate comprising 250 small-scale factories. The study shows that the cost burden of water pollution abatement is much higher for small factories providing greater cost advantage to treat effluents jointly in a Common Effluent Treatment Plant (CETP). The primary treatment costs (with CETP) and total abatement costs (without CETP) are estimated. The costs of abatement under alternative institutional arrangements have also been estimated. The study finds that the institutional arrangement of the Common Effluent Treatment Plant is necessary to internalize the water pollution externalities for small-scale factories. Large potential welfare gains can be generated from such institutional arrangements.

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* Department of Economics, Miranda House, Delhi University, Delhi 110 007, INDIA. This paper is a part of my doctoral dissertation to be submitted to the University of Delhi.

1. Introduction

The potential benefits from industrial water pollution abatement at Nandesari Industrial Estate comprising 250 small-scale factories has been estimated for six villages and for the city of Vadodara using the contingent valuation method (Misra, 1997). As a next step, it is important to estimate the cost to factories for complying with State Pollution Control Board standards. The cost of industrial pollution abatement continues to worry policy makers as hardly any empirical evidence is available in this area. As far as small-scale factories are concerned, there is in fact *no empirical evidence* on the costs of meeting standards and this study is an attempt to bridge that gap. Information about abatement costs would be extremely useful for designing cost-effective regulation since small-scale factories continue to be a major source of water pollution in India. This study examines in detail the effluent control behavior of small-scale factories and the costs they have to bear for water pollution abatement.

The case of Nandesari Industrial Estate is interesting to study because effluent treatment is at two stages: a primary treatment within the factory premises mainly for controlling chemical oxygen demand, dissolved solids and suspended solids and a secondary treatment with the help of a Common Effluent Treatment Plant (CETP) for controlling biological oxygen demand. This *two-step treatment method* is an illustration of how small-scale factories can benefit from economies of scale in water pollution abatement technology.

The cost of effluent control at Nandesari Industrial Estate is estimated for the following: (a) a primary abatement cost for effluent control at the level of each factory to treat effluents in accordance with the technological requirements of the CETP and (b) a secondary cost of effluent control for treatment at the CETP to meet the State Pollution Control Board (SPCB) norms. In addition, (c) a total abatement cost function has been estimated for complete effluent control at the level of each factory to meet the SPCB norms in the absence of a CETP.

This paper shows that there are benefits in treating factory effluents jointly, which arise from considerable economies of scale associated with the provision of wastewater treatment services. Increased flow from industrial enterprises to the CETP made possible by large scale participation reduces the average treatment costs. This provides incentives for small-scale factories to engage in joint treatment facilities or common effluent treatment plants. Nandesari Industrial Estate plays a role model in this respect.

The paper is organized as follows: section 2 discusses briefly the industrial pollution and control in India; section 3 deals with some conceptual and methodological issues in the estimation of cost function; section 4 discusses the data and variables used in this study; section 5 presents estimates of the primary abatement cost function; section 6 presents estimates of the total abatement cost function; section 7 gives the estimated price elasticities and the elasticities of cost with respect to wastewater volume and post-treatment pollution concentration level; section 8 deals with the average and marginal costs of treatment; section 9 discusses the costs of abatement under alternate institutional arrangements and section 10 presents the conclusions.

2. Industrial Pollution Control in India

Growing industrialization and accompanying urbanization have placed increasingly competitive demands on the nation's common property resources such as water. During the past decade, there has been increasing concern about misallocation of resources and environmental degradation. Various environmental regulations provide the necessary support for and are a reflection of a national concern about the levels of environmental degradation. The Water (Prevention and Control of Pollution), Act, 1974, amended in 1986; the Water (Prevention and Control of Pollution) Cess Act, 1977, amended in 1988; the Environment Protection Act, 1986 are the most important laws pertaining to industrial pollution abatement in India. These laws set national goals for eliminating the practice of discharging pollutants into rivers without providing the required treatment and there are specific guidelines for effluent discharges from all sources. Although there have been various legislations in India empowering Central and State governments to implement these regulations, these attempts have not been successful. Strict laws have been enacted, but it is common knowledge that the administrative machinery has not been able to enforce the regulation (Murty 1995, Gupta 1996). Murty (1995) shows that industry and bureaucracy have incentives to collude for sharing the costs saved from non-compliance of environmental standards by the industry. Gupta (1996) argues that the division of environmental functions between the central, state and local levels reflect the underlying tension over the distribution of power and the institutional framework dealing with environmental issues is of fairly recent origin and is still very weak.

Welfare economics suggests government intervention as the only solution to deal with situations of market failure (Pigou, 1932, Baumol, 1972). However, direct regulation on effluent discharge cannot work for small-scale factories since they are afflicted with problems of resource, space and technology (Misra and Murty, 1995). Hence command and control regulations in India have not proved very effective for controlling water pollution in small-scale factories. Infact they have failed! The result of a strict application of command and control regulations in the case of small-scale factories could be either (1) small-scale factories incur pollution abatement at a very high cost, or (2) they continue to pollute because compliance with the legislation imposes large abatement costs. Rather than bearing the costs imposed by a heavy environmental regulation which substantially erodes their profitability, the small-scale factories find it is easier to bribe the regulatory authority and thus continue environmental degradation. Hence the failure of government in dealing with water pollution problem relating to small-scale factories is mainly due to (a) high cost of abatement, (b) non-benevolent behaviour of the government and (c) prohibitively high policing costs.

It is therefore imperative to investigate how externalities maybe internalized for a cluster of small-scale factories. The Nandesari case does not show how market mechanism can be revived. *It basically shows that without the institution of CETP, internalization of the externalities is not possible*. The existing technology of water pollution abatement suggests that there are increasing returns to scale with respect to pollution loads. Some empirical studies about the cost of technological processes for water pollution abatement confirm the presence of increasing returns to scale (Dasgupta and Murty 1985; Batstone and others 1989; Mehta, Mundle and Sankar, 1993; James and Murty 1996). James and Murty have estimated a water pollution abatement cost function using data for an all India sample of 131 factories drawn from 17 highly water polluting industries. They have found decreasing marginal cost with respect to volume of wastewater for the given levels of concentration of Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD).

3. Conceptual Issues

3 (a) A Critical Review of some Recent Studies

There have been several studies on the cost of pollution abatement for industries in India in which the cost behaviour has been analyzed with the help of an estimated abatement cost function. Some of these studies have used a Cobb-Douglas function while some others have made an attempt to use the translog functional specification (the results have, however, not been satisfactory). A careful examination of the methodologies adopted in these studies reveals certain serious inadequacies and for this study a different approach has therefore been taken. Before explaining the methodology adopted, the inadequacies of the earlier studies may be discussed briefly.

Some of the earlier studies in this area e.g. Rossi, Young and Epp (1979), Fraas and Munley (1984) have several problems of interpretation with the framework they use (Goldar and Mukerji, 1998). Problems of interpretation arise because what constitutes the output of the abatement activity is not clearly defined. Also, there are certain inadequacies in the functional specifications used in some of these studies.

Rossi, Young and Epp (1979) specify the production function associated with water pollution abatement as:

$$O = f(N, I) \tag{1}$$

where O is the vector of flow and quality characteristics of effluent stream, N is the vector of flow and quality characteristics of influent stream and I is the vector of factors of production. The corresponding cost function would be:

$$C = g(O, N, P) \tag{2}$$

where C is the cost and P is the vector of prices of factors of production.

There are several problems of interpretation with (1) and (2). N cannot be treated as an input in the same way as I (Goldar and Mukerji, 1998) as labour and capital cannot substitute the volume and characteristics of influent stream. Also, volume and characteristics of the effluent stream cannot be taken as the output of the production function. There are problems in interpreting the partial derivatives of O with respect to I and N. Another problem is that, given I and N, the vector O is not unique since the abatement activity may be directed more at one pollutant rather than another. This is specially true for a cluster of small-scale factories where pollution abatement could be at two stages, primary treatment at the factory level and a secondary treatment at the CETP level.

Other problems arise with respect to the kind of specifications used. For Indian industries, James and Murty (1996) have used the following cost function specification:

$$\ln C = a + \alpha \ln V + \beta \ln (qi / qe) + \Sigma\, bj \ln pj \tag{3}$$

whereas Roy and Ganguli (1997) and Goldar and Pandey (1997) have used the following:

$$\ln C = a + \alpha \ln V + \beta \ln qi + \mu \ln qe + \Sigma\, bj \ln pj \tag{4}$$

where C is the total cost of abatement, V is the volume of water treated, qi is the level of a particular pollutant `i' in the influent stream, qe is the level of the pollutant in the effluent stream and pj are the input prices of labour, capital, energy, materials etc.

There are several problems with the above specifications:

(i) A measure of output (Y) corresponding to Goldar-Pandey specification (equation 4) is

$$Y = AV^{\alpha}\, qi^{\beta}\, qe^{\mu} \tag{5}$$

The interpretation of this expression is not clear with respect to the work done by the abatement plant. This problem arises because the output of the abatement activity is not clearly defined and the form of the cost function has not been deduced from a production function.

(ii) Corresponding to the James-Murty cost function the output definition should be

$$Y = AV^{\alpha} (qi / qe)^{\beta} \tag{6}$$

Again, the meaning of this expression is not clear. Further, one may ask: What is the unit of measurement of output in (5) and (6)?

(iii) The derivation of the cost function from the production function requires that the prices of all inputs be taken as arguments in the cost function. This has, however not been done in studies on abatement cost function for Indian industries. Some studies have not taken prices of inputs at all (Mehta, Mundle and Sanker, 1993) while other studies have taken prices of some but not all inputs (James and Murty, 1996; Goldar and Pandey, 1997). The main problem these studies faced in including input prices in cost function was that they used cross-section data and hence there was absence of inter-factory variation in prices of some inputs.

(iv) The variables qi and qe have the same coefficient in the James-Murty (1996) model which involves a restrictive assumption. This can be tested and the results of Goldar-Pandey (1997) for distilleries indicate that this assumption is not justified.

(v) Even if qi=qe (for James-Murty and Goldar-Pandey model), the abatement cost does not go to zero, with the consequence that the estimated cost function will overstate the cost of abatement at low levels of abatement. This affects the estimates of marginal abatement cost.

(vi) Due to high intercorrelation among BOD, COD etc., cost function has been estimated separately for each. However, then one does not get the proper marginal costs[1].

(vii) In the James- Murty model, cost of abatement is determined by the percentage reduction in pollutant concentration level. But, the cost of reduction of BOD level from 1000 to 500 mg / litre is likely to be different from that of reducing BOD level from 500 to 250 mg / litre. It is important therefore that in the estimated cost function, the initial or the post-treatment level of pollutant concentration be included as an additional variable.

(viii) Elasticity of cost with respect to qe is a constant in all the studies mentioned above. This is clearly a restrictive assumption.

(ix) Although data from diverse industries are pooled in some of the above studies, dummy variables are not used to take into account inter-industry differences.

3 (b) Methodology

The methodology adopted for deriving the cost function in this study is presented below. First, the approach taken is discussed, followed by details of the methodology.

Generally in econometric studies on cost function, cost is taken as a function of output of the activity and prices of inputs. The same approach needs to be taken for the abatement cost function. Thus the output of the abatement plant can be specified as

$$Y = Y(O, N) \tag{7}$$

[1] Given a variety of pollutants like Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Solids (SS), Dissolved Solids (DS) etc, there is problem of multicollinearity as these pollutants are found to be highly correlated with each other. This problem has important implications for evaluating the marginal cost of abatement. The marginal cost cannot be computed separately for each pollutant unless they are all included in the estimated regression (Goldar and Mukerji, 1998).

where Y is the output of the abatement plant, O is the vector of flow and quality characteristics of effluent stream and N is the vector of flow and quality characteristics of influent stream.

The production function corresponding to this definition of output is

$$Y = f(I) \tag{8}$$

where I is the vector of factors of production. Given the production function in equation (8), the cost function is

$$C = g(Y, P) \tag{9}$$

where P is the vector of input prices.

The above formulation of production function and cost function avoids the problems of interpretation arising in earlier studies. The production of the abatement plant is viewed as a '*service activity*' or '*work done*' to reduce the level of pollution. The output of the abatement plant is the extent of pollution reduction achieved for each pollutant for a given volume of wastewater treated. Given a fixed volume of water treated (V), typically for estimating abatement cost functions from *time-series data* for a firm whose production level and wastewater discharge level does not change over time, the output of the abatement plant could be written as:

$$Y = y\,V \tag{10}$$

and

$$y = (qi - qe) \tag{10 a}$$

where qi is the level of a particular pollutant in the influent stream, qe is the level of the pollutant in the effluent stream and y measures the output of the abatement plant in terms of a reduction in pollution load per litre of wastewater treated. The term qi-qe implies a reduction in the pollution concentration level (milligrams per litre). The advantage of this specification is that it takes care of the problems discussed above with respect to qi and qe. The initial level of pollution concentration, qi may be taken as given. Thus, a higher level of qe implies a lower output and a lower level of qe implies a higher output. Hence the output is negatively related with qe.

For a Cobb-Douglas functional specification, assuming there are only two inputs, labour and capital, the production function is:

$$Y = AL^{\alpha}K^{\beta} \tag{11}$$

where L and K denote labour and capital input for treatment of wastewater. Let w be the wage rate and r the rental of capital, then the cost of treatment of wastewater is given by:

$$C = wL + rK \tag{12}$$

Assuming that the factory minimizes the cost of treatment, given prices of inputs and volume of wastewater, the corresponding cost function could be derived as[2]:

$$C = B\, w^{\gamma}\, r^{1-\gamma}\, y^{\delta} \tag{12a}$$

and it can be shown that,

$$\gamma = \alpha \;/\; (\alpha + \beta) \;\text{ and }\; \delta = 1 \,/\, (\alpha + \beta) \tag{13}$$

The Cobb-Douglas specification requires that α, β and γ should be positive. The exponents of w and r must add up to unity since the cost function is homogeneous of degree one in input prices. In order to achieve lower levels of qe, the inputs required also increases and after a point further reductions in qe are increasingly difficult, requiring more than proportionate increase in inputs reflected as diseconomies of scale in the production function. Hence, $\alpha + \beta$ should be less than 1 and δ should be greater than 1. The functional form given above can be easily extended to more than two inputs. Also, one may use the translog functional form instead of the Cobb-Douglas functional form used above.

In the cost function specification above, only one pollutant has been considered. A useful extension of the cost specification could be a multi-output cost specification. A multi-output cost function will have various outputs as its arguments.

$$C = f\,(Y_{COD}, Y_{BOD}, Y_{SS}, Y_{DS}, pl, pk, pm, pe), \tag{14}$$

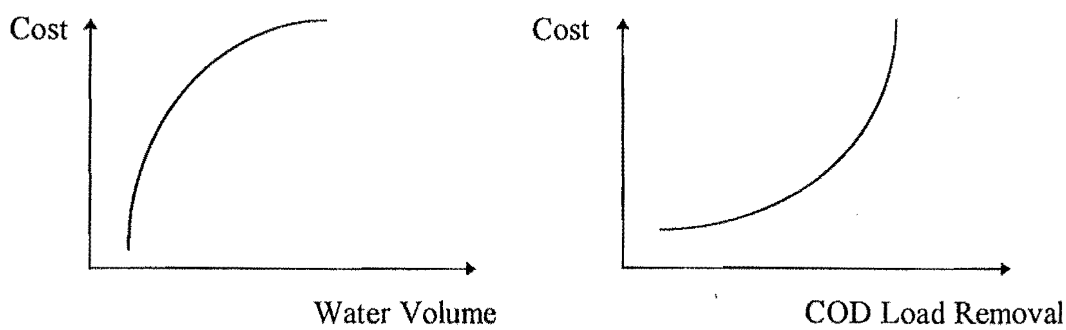
where, C is the cost of abatement, BOD, COD, DS, SS are different pollutants, pl is the price of labour, pk is the price of capital, pm is the price of materials and pe is the price of energy. However, experience gained in empirical research bring out that there is a high correlation among the extent of reduction of different pollutants making it difficult

[2] The derivation of the cost function is in Goldar and Mukerji, 1998.

empirically to estimate the cost implications of the different components of output. It may be necessary therefore to use one of the pollutant as an overall indicator of the pollution level and the extent of abatement done.

The cost of abatement is expected to vary in a dissimilar manner with respect to volume of wastewater treated and the extent of abatement (Figure 1). As the volume of water treated increases, the cost of abatement will increase less than proportionately due to economies of scale in treating a larger volume of water but as the extent of abatement increases, the marginal cost will increase as further reduction in the pollution level becomes more and more difficult. Also, economies of scale need not be prevalent for all pollutants. There may be economies of scale in treatment of BOD but no such economies of scale in treatment of COD, SS or DS. This is very true for a cluster of small-scale factories. For Nandesari Industrial Estate, some reduction in the levels of COD, SS and DS are made during primary treatment at the factory whereas BOD and COD are reduced to meet SPCB standards at the CETP. This is indicative of economies of scale in treating larger volumes of water for BOD and COD but no such economies for SS and DS.

Figure 1



Economies of scale in treatment of wastewater should be checked by analyzing variation in abatement costs across firms of different size. For estimating the cost function given in equation (12) above from cross-section data, some modification becomes necessary. The volume of water treated will have an influence on cost of treatment per litre. Also, the post-treatment pollution concentration level has to be included in the cost function[3]. Accordingly, the cost function is specified as:

[3] The need for including V and qe as additional variables in the cost function has been discussed by Goldar and Mukerji (1998). They point out that one may use qi or qe to take into account inter-firm

$$C = A\, w^{\gamma}\, r^{1-\gamma}\, (qi - qe)^{\delta}\, V^{\in}\, (qe)^{\mu} \qquad (15\ a)$$

In the discussion above, a two-input production function has been assumed for ease of exposition. For this study, a three-input model has been used taking labour (l), capital (k) and materials plus energy (me) as three inputs. Accordingly, the cost function using the Cobb-Douglas functional form in (15 a) has been specified as:

$$\ln C = A + \delta \ln (q_i - q_e) + \in \ln V + \mu \ln (q_e) + \alpha_l \ln p_l + \alpha_k \ln p_k + \alpha_{me} \ln p_{me} \qquad (15\ b)$$

where pl = price of labour; pk = price of capital; and pme = price of materials plus energy. Since the cost function must be linear homogeneous in input prices, α_l, α_k and α_{me} must add to one.

A serious limitation of Cobb-Douglas (CD) functional form is that the elasticity of substitution is unity between each pair of inputs. This format assumes substitution possibilities to be the same and does not allow complimentarity between any pair of inputs. One way of getting over this problem is to use a Transcendental Logarithmic (translog) functional format. The translog specification is a more general specification than the Cobb-Douglas specification. It allows the possibility of testing whether Cobb-Douglas can be taken as the right specification for cost functions. The translog functional format is linear in its parameters and provides second order approximation in input prices to an arbitrary continuously differentiable cost function. Also, it is known from Shepherd's duality theorem that the econometric estimation of the parameters of a cost function is equivalent to estimating the parameters of the underlying production function, provided producers behave competitively in the factor markets.

Using the translog specification, the cost function may be written as:

$$\ln C = A + \delta \ln (q_i - q_e) + \in \ln V + \mu \ln (q_e) + \Sigma\, \alpha_j \ln p_j + 1/2\, \Sigma\, \Sigma\, \beta_{zj} \ln p_z \ln p_j$$
$$+ \Sigma\, \gamma_j \ln V \ln p_j + \Sigma\, \varphi_j \ln (q_i - q_e) \ln p_j + \Sigma\, \lambda_j \ln q_e \ln p_j \qquad (16\ a)$$

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differences in initial and post-treatment levels of pollution concentration level, but advance argument in favour of inclusion of qe as an explanatory variable in the cost function.

where,

$$\beta_{zj} = \beta_{jz}$$

The conditions necessary for the translog form to be linearly homogeneous in input prices are:

$$\sum_j \alpha_j = 1, \quad \Sigma \beta_{zj} = 0, \quad \text{for } z = l, k, me$$

$$\Sigma \gamma_j = 0, \Sigma \varphi_j = 0 \text{ and } \Sigma \lambda_j = 0, \quad \text{for } j = l, k, me$$

For this study, translog cost function has been estimated along with cost share equations using the LIMDEP software. The seemingly unrelated regression estimates (SURE) procedure is used. While estimating the parameters of the cost function and cost share equation, appropriate restrictions on parameter estimates are imposed both within equations and across equations. Thus the parameter estimates are obtained such that the conditions of linear homogeneity are satisfied.

A truncated version of the above model has also been estimated in which the interaction terms involving ln V, ln (qi-qe) and ln qe are dropped, i.e. one assumes, $\gamma_j = \varphi_j = \lambda_j = 0$ for j = l, k and me. Thus equation 16a reduces to

$$\ln C = A + \delta \ln (q_i - q_e) + \in \ln V + \mu \ln (q_e) + \Sigma \alpha_j \ln p_j + 1/2 \, \Sigma \Sigma \beta_{zj} \ln p_z \ln p_j \qquad (16\text{ b})$$

We shall be referring to this model as truncated translog model (and the model in equation 16a as the full translog model). The truncated translog model has relatively fewer parameters and is therefore easier to estimate, but the full translog model provides greater flexibility and is obviously superior in terms of functional specification. The full translog has a flexible functional format and has been successfully used in this study to estimate the cost of abatement at Nandesari[4]. The cost share equations can be derived as

$$Sj = pj\, Xj / C = \partial \ln C / \partial \ln pj \qquad j = l, k, me \qquad (17)$$

The cost share equations for labour, capital and materials-energy for the full translog model are as follows:

$$Sl = \alpha_l + \beta_{ll} \ln p_l + \beta_{lk} \ln p_k + \beta_{lme} \ln p_{me} + \gamma_l \ln V + \varphi_l \ln (q_i - q_e) + \lambda_l \ln q_e \qquad (17\text{ a})$$

[4] To the best of the author's knowledge, there is no study on abatement cost function in the Indian context in which a full translog specification has been used.

$$Sk = \alpha_k + \beta_{lk} \ln p_l + \beta_{kk} \ln p_k + \beta_{kme} \ln p_{me} + \gamma_k \ln V + \varphi_k \ln (q_i - q_e) + \lambda_k \ln q_e \quad (17\ b)$$

$$Sme = \alpha_{me} + \beta_{lme} \ln p_l + \beta_{kme} \ln p_k + \beta_{meme} \ln p_{me} + \gamma_{me} \ln V + \varphi_{me} \ln (q_i - q_e) + \lambda_{me} \ln q_e \quad (17\ c).$$

where Sl = share of labour, Sk = share of capital, Sme = share of materials plus energy.

Since three inputs have been considered, cost shares for any two inputs have to be used along with the cost function. In this study, cost share equations for (i) labour and (ii) materials plus energy inputs have been chosen for estimation.

4. Data and Variables

Time series primary data (for the years 1993-94 to 1995-96) were collected for a sample of 45 factories from Nandesari Industrial Estate comprising 250 small-scale factories producing different kinds of organic and inorganic chemicals and pharmaceuticals. A questionnaire was designed to collect information about costs of abatement from the sample factories providing primary treatment during 1993-94 to 95-96. Detailed information was collected about the labour costs, capital costs, material costs and energy (fuel and power) costs over the three years using stratified random sampling method for factories producing organic, inorganic and pharmaceutical products. The data on the volume and characteristics of influent wastewater and effluent wastewater were collected from the records maintained by the factory owners for Nandesari Association as well as SPCB.

This study uses pooled data for 38 factories for a period of three years, 1993-94, 1994-95 and 1995-96. Sample data of seven factories were excluded because of incomplete reporting. Besides data on abatement activity, data were collected on the revenue of the production unit (factory), and detailed data on the input costs. The data set used for this study includes the wage bill, number of workers, fuel and energy prices and expenditure, price and quantity of materials used and the expenditure on capital equipment for the three years both for the main production plant and for the effluent treatment plant

(ETP). The advantage of using a pooled data set (with intertemporal variations in prices) is that prices of all inputs can be used in estimating the abatement cost function. This is a considerable improvement over the earlier attempts at estimating abatement cost functions.

This study uses a three input model. Capital is taken as one input, labour as another. Materials and energy are taken together as one input. Cost of abatement is obtained as the sum total of costs with respect to these three inputs. For estimating the cost function, prices of inputs are needed. Standard procedure was adopted to calculate the price of capital services. Price of capital service is obtained as:

$$pk = pi\ (r + d), \qquad (18)$$

where pk = price of capital input (service), pi = price index of capital goods, r = rate of return on capital and d = rate of depreciation.

For computing the price index of capital goods pi, the wholesale price index of machinery was taken for the three years as reported in Economic Survey, 1997. A measure of stock of capital goods was formed by expressing the value of capital assets in the three years at 1996 prices. The rate of return on capital, r was obtained as follows:

Value Added by capital = Total Revenue - Wage Bill (Main Plant + ETP) -Materials and Energy Cost (Main Plant + ETP)

Rate of return on capital = Value Added by capital / (Value of assets in Main Plant + Value of assets in ETP)

The reported rate of depreciation was used for each factory. From r, d and pi, the price of capital pk was computed. This multiplied by the quantity measure of capital stock yielded the annual cost of capital input for the abatement which as pointed out above is a component of the total abatement cost.

The price of labour was calculated as the wage bill divided by the number of labourers used for the ETP. Earlier studies on abatement cost function for Indian industries have also used this method to derive the price of labour input.

A weighted price index was constructed for raw materials used in the ETP. Generally, four types of materials are used for primary treatment at ETPs in Nandesari Industrial Estate. These are ferrous sulphate, hydrated lime, soda ash and caustic soda. For 3 million litres of wastewater, about 4000 Kg ferrous sulphate, 500 Kg hydrated lime, 550 Kg soda ash and 500 Kg caustic soda are needed. The following table shows the weighted price index of raw materials used in the ETP for the three years.

Table 1 Price Index of Raw Materials (1995-96 = 100)

	Hydrated Lime	Soda Ash	Caustic Soda	Ferrous Sulphate	Weighted Average
1993-94	66.66	86.36	66.66	70	71.76
1994-95	83.33	90.90	133.33	80	96.77
1995-56	100	100	100	100	100.00

Note: weights are the share of the raw material in the total cost of raw materials.

A price index of energy and fuel (e) used for ETP was computed for the three years. A combined weighted price index of materials and energy (me) was then computed, the respective weights being the relative share of materials and energy in the total cost of materials plus energy used in the ETP.

In this way the price of labour, price of capital and a combined price of materials and energy used in the ETP was obtained with intertemporal as well as inter-factory variations[5].

Besides collecting data on abatement cost for the sample factories, such data were collected for the CETP. Another questionnaire was designed for this purpose to collect similar data from CETP for providing a joint secondary level treatment to meet the SPCB norms. The data for capital costs and operation and maintenance costs of the CETP were obtained for 1995-96 and 1996-97.

[5] There are intertemporal variations in prices of labour and capital services over the three year period and inter-factory variations for each year. The price index for materials and price index for energy vary over the three year period but are the same for each factory observation in each year. These indices have been combined to get a weighted price index of materials plus energy using factory specific expenditure on materials and energy for abatement activity in each year. This introduces inter-factory variation in price of materials plus energy in each year.

One important question investigated in this study is how far small-scale units can save the cost of wastewater treatment by setting up CETP. It was necessary therefore to find out what cost the factories will have to bear if they have to undertake complete treatment. Accordingly, a separate part of the questionnaire for factories collected information about additional costs of abatement the factories will have to incur to meet SPCB standards in the absence of a CETP. This part requested factory owners to give an estimate of additional abatement costs necessary to meet the SPCB standards if total abatement was undertaken at the factory level. The factory owners provided information about the additional cost for labour, materials, energy and fuels and the additional investment in capital assets.

The sample information gives the mean price of labour as Rs 24,257 per annum (s.d. = Rs 18,240). The mean price index of capital services is 1.11 (s.d. = 0.91) and mean price index of materials plus energy is 87.10 (s.d. = 12.9). The average volume of wastewater discharged is 7.3 million litres per annum. It ranges from 0.1 million litres per annum to 69 million litres per annum. The initial level of COD concentration ranges from 100 mg per litre to 10,000 mg per litre. On an average, the initial level of COD concentration is 3450 mg per litre. The reduction of COD concentration during primary treatment, on an average is 2615 mg per litre. The cost of primary water pollution treatment on an average per factory is Rs 1.5 million per annum. It ranges from Rs 0.04 million to Rs 13.9 million per annum. If the factory has to undertake total water pollution abatement at the factory level (complying with SPCB standards), the average *additional* cost burden per factory is Rs 1.4 million per annum, ranging from Rs 60,000 to Rs 8 million per annum.

5. Primary Cost of Water Pollution Abatement

The estimation of the primary abatement cost function has been based on factories' reported direct costs of installing and operating water pollution control equipment[6]. The translog specification has been used to estimate the costs of abatement. The estimates of translog cost function parameters are presented in Table 2. The notation for variables is as follows:

V	=	volume
dci	=	(qi - qe) influent concentration of COD - effluent concentration of COD
qe	=	effluent concentration of COD
pl	=	price of labour
pk	=	price of capital services
pme	=	price index of materials and energy

From Table 2, which gives the estimates of primary abatement cost functions using both full and truncated translog specifications, it is seen that the models fit the data well as indicated by the values of R^2. Most coefficients are found to be statistically significant. The coefficient of V in full translog is less than 1 showing there are economies of scale in industrial water pollution abatement for small-scale factories. The coefficient of variable dci is positive showing that the greater is the difference between the influent concentration and effluent concentration of COD, the greater is the primary cost of abatement. The coefficient of qe is negative showing that the lower is the concentration of COD effluent to be achieved, the higher will be the primary cost of abatement. Price of capital and labour are highly significant in explaining the primary cost of abatement.

Restrictions on parameters reduce the full translog model to the restricted translog model and further to the Cobb-Douglas model. In cost function studies, these alternative specifications are commonly tested with 'likelihood ratio test' (Greene 1993). In this case,

[6] Given the multicollinearity problem between BOD, COD, SS and DS pollutants, one of them has to be chosen as the measure of pollution level. The CETP at Nandesari has a technological requirement for the COD concentration level to be reduced in the range of 250 - 1500 mg per litre at the factory level. The Nandesari Association regularly monitors the COD effluent from factories to enable the proper functioning of the CETP. Hence COD is the obvious choice for a measure of pollution level in this study.

the likelihood ratio statistic is 273.46 (d.f. = 9) for the restrictions that reduce the full-translog model to Cobb-Douglas and 41.26 (d.f. = 6) for the restrictions that reduce the full translog model to the truncated translog model. Both are statistically significant at one percent level and therefore both the truncated translog and Cobb-Douglas model are rejected. Also, R^2 and Adjusted R^2 are distinctly better in the full translog model as compared to the truncated translog model for the estimates of the cost share equations[7]. Therefore the full translog model is superior to the truncated version and has been used for the estimation of primary water pollution abatement costs for Nandesari Industrial Estate.

The condition of monotonicity for a well-behaved translog function requires that $\partial C / \partial pj > 0$ for j = l, k and me. This condition implies that the share of factor inputs should be positive. This has been checked and it is found that the estimated share equations in the full translog model satisfy this condition.

6. Total Cost of Water Pollution Abatement

The estimate of primary abatement cost function presented in the previous section was based on data relating to actual cost of wastewater treatment in factories. Since the factories are doing only primary treatment, the estimated cost function can be used to get estimates of primary treatment costs. It is reasonable to argue that the cost function estimates presented above may not give the right estimates of abatement cost, if the factories have to undertake total abatement. To get over this problem, this study estimates the abatement cost function from an enlarged data set in which the additional abatement cost to undertake total abatement at the factory level is provided by the 38 factories.

7

	Truncated translog		Full Translog	
	Sl	Sme	Sl	Sme
R^2	0.43	0.21	0.46	0.42
Adjusted R^2	0.42	0.19	0.43	0.39

Note: Sl= share of labour; Sme = share of materials and energy.

Hence, this part of the study uses the *additional* abatement cost data provided by 38 factories if they have to undertake total abatement at the factory level (in the absence of a CETP) to meet the SPCB norms. The factories were asked to give details of the *additional costs* they will have to incur in order to meet SPCB standards in the absence of a CETP[8]. The additional cost for total abatement was added to the actual costs for primary abatement to get an estimate of the total cost of abatement at the level of each factory. The functional specifications and the method of estimation used are the same as in the previous section.

Table 2 also presents the results of the translog specifications for estimating the total abatement costs for Nandesari. Both full and truncated translog forms have been used. The results are similar to the estimation of primary abatement cost. The coefficient of V is less than 1 indicating the presence of economies of scale in industrial water pollution abatement for small-scale factories. The variable dci has a positive coefficient showing that the greater is the difference between the influent concentration and effluent concentration of COD, the greater is the total cost of abatement; the coefficient of qe is negative which is the correct sign showing, the lower is the concentration of COD effluent to be achieved, the higher will be the total cost of abatement. Price of capital and labour are very significant in explaining the total cost of abatement.

The likelihood ratio test statistic is 388.2 (d.f.= 9) for the restrictions that reduce the full-translog model to Cobb-Douglas and 46.58 (d.f. = 6) for the restrictions that reduce the full translog model to the truncated translog model. Both are statistically significant at one percent level and therefore both the truncated translog and Cobb-Douglas model are rejected. Also, the R^2 and Adjusted R^2 are higher for the full translog model as compared with the truncated translog model for the estimates of the cost share

[8] It should be pointed out that while making estimate of cost function based on cost of primary treatment data, three observations (for the three years, 1993-94, 94-95 and 95-96) were used for each factory giving a total of 114 observations. After adding the additional cost of abatement we get one more observation for each factory. Thus a panel of four observations for each of the 38 factories giving a total of 152 observations was used for the estimates presented in this section.

equations[9]. Thus, the full translog model is preferable to the truncated translog model and has been used for estimating the total cost for water pollution abatement at Nandesari Industrial Estate.

The condition of monotonicity for a well-behaved translog function requires that $\partial C / \partial pj > 0$ for j = l, k and me. This condition implies that the share of factor inputs should be positive. The estimated share equations in the full translog model satisfy this condition.

9

	Truncated Translog		Full Translog		
		Sl	Sme	Sl	Sme
R^2	0.49	0.21	0.51	0.38	
Adjusted R^2	0.48	0.19	0.49	0.36	

Note: Sl= share of labour; Sme = share of materials and energy.

Table 2

Estimates of Cost Function for Water Pollution Abatement at Nandesari Industrial Estate
Dependent Variable ln C

Explanatory Variables	Primary Cost of Abatement: Truncated Translog	Primary Cost of Abatement: Full Translog	Total Cost of Abatement: Truncated Translog	Total Cost of Abatement: Full Translog
ln V	0.337	0.602	0.320	0.564
	(6.555)***	(5.977)***	(7.200)***	(6.474)***
ln dci	0.297	0.391	0.297	0.435
	(6.571)***	(4.555)***	(7.924)***	(6.073)***
ln qe	-0.253	-0.047	-0.282	-0.193
	(-3.083)***	(-0.307)	(-4.560)***	(-1.662)*
ln pk	1.907	1.454	1.906	1.523
	(17.652)***	(7.787)***	(23.072)***	(10.571)***
lnpk*lnpk	0.166	0.152	0.163	0.153
	(13.419)***	(11.696)***	(17.123)***	(15.089)***
ln pl	-0.927	-0.502	-0.937	-0.650
	(-7.120)***	(-2.727)***	(-9.176)***	(-4.584)***
lnpl*ln pl	0.123	0.133	0.122	0.131
	(6.836)***	(7.845)***	(8.390)***	(9.423)***
ln pme	0.0206	0.049	0.031	0.128
	(0.199)	(0.354)	(0.370)	(1.143)
lnpme*ln pme	0.085	0.100	0.078	0.087
	(4.209)***	(5.116)***	(4.559)***	(5.041)***
ln pl*lnpk	-0.102	0.152	-0.103	-0.098
	(-9.267)***	(11.696)***	(-12.136)***	(-10.941)***
ln pl*ln pme	-0.0208	-0.041	-0.019	-0.033
	(-1.248)	(-2.633)***	(-1.346)	(-2.432)***
ln pk*ln pme	-0.0638	-0.060	-0.060	-0.054
	(-5.911)***	(-5.657)***	(-6.744)***	(-6.160)***
ln v*ln pl		-0.036		-0.030
		(-3.645)***		(-3.777)***
ln v*ln pk		0.011		0.011
		(1.117)		(1.374)
ln v*ln pme		0.025		0.019
		(3.131)***		(2.820)***
ln dci*ln pl		0.009		0.004
		(1.031)		(0.543)
ln dci*ln pk		0.025		0.026
		(2.937)***		(3.807)***
ln dci*ln pme		-0.034		-0.029
		(-5.188)***		(-5.457)***
ln qe*ln pl		-0.027		-0.011
		(-1.736)*		(-0.969)
lnqe*ln pk		0.011		0.006
		(0.710)		(0.522)
lnqe*lnpme		0.016		0.005
		(1.264)		(0.517)
constant	13.002	8.479	13.421	9.689
	(15.870)***	(5.981)***	(20.311)***	(8.442)***
number of observations	114	114	152	152
R^2	0.65	0.66	0.65	0.66
Adjusted R^2	0.61	0.58	0.62	0.61

t-ratios are in parenthesis; *** significant at 1 percent ; ** significant at 5 percent; * significant at 10 percent.

7. Price Elasticities and Cost Flexibility

The advantage of the translog specification is that it does not assume the elasticity of substitution between factors of production to be constant. Hence, the elasticity of substitution and the price elasticity can be computed using the translog specification[10] for labour (L), materials-energy (M) and capital (K). These elasticities have been computed from the estimated full translog model for both primary cost and total cost function. Table 3 shows (as expected) that the own price elasticities are negative. Also, labour, capital and materials-energy are substitutes as the elasticity of substitution are positive for them. Since for both models, price elasticities are low, it may be inferred that the substitution possibilities among labour, capital and materials-energy are limited.

Table 3 Elasticities

Own Price Elasticity	Primary Cost Model	Total Cost Model
LL	-0.20	-0.19
MM	-0.33	-0.37
KK	-0.17	-0.17
Cross Price Elasticity		
KL	0.07	0.04
LK	0.17	0.11
ML	0.05	0.08
LM	0.05	0.08
MK	0.29	0.33
KM	0.11	0.13
Cross Elasticity of Substitution (Allen)		
LK	0.30	0.19
LM	0.21	0.38
KM	0.51	0.59

[10] The own elasticity of substitution can be estimated for labour as, $(\sigma ll) = (\beta ll + (Sl)(Sl-1)) / (Sl*Sl)$ where Sl = share of labour in total cost; price elasticity of labour $(\eta l) = (\sigma ll) * Sl$ and cross elasticity of substitution of labour for capital, $(\sigma lk) = (\beta lk + (Sl)(Sk)) / (Sl*Sk)$, where Sk = share of capital in total cost. From cross elasticities of substitution, cross price elasticities can be derived.

Elasticities of substitution and price elasticities (own and cross) are parameters of interest that can be derived from an estimated cost function. Another parameter of interest is the effect of volume of wastewater treated on the cost of treatment. Similarly, the effect of lowering post-treatment pollution concentration level on treatment cost would be important to estimate. These require that the total effect of V and qe on C be computed[11]. In the translog specification, due to the existence of various interaction terms, the total effect of a variable, say V cannot be directly read from the estimated equation. However, the total effect can be computed at the sample mean by differentiating the estimated cost function and setting the various explanatory variables at the sample mean.

Table 4 Cost Flexibility

	$\partial \ln C / \partial \ln V$	$\partial \ln C / \partial \ln qe$
Primary Treatment	0.35	-0.50
Total Abatement	0.35	-0.43

The *total effect* of volume of wastewater treated on the cost of abatement (i.e., $\partial \ln C / \partial \ln V$) has been computed by this method for the estimated primary and total cost functions. The computed elasticities gives the returns to scale in wastewater treatment. Table 4 shows there are considerable economies of scale in wastewater treatment as $\partial \ln C / \partial \ln V = 0.35$ both for primary as well as total costs of abatement (which implies that a 10 percent increase in water volume leads to 3.5 percent increase in treatment cost). Also, the total effect of effluent characteristic of COD on the cost of abatement (i.e. $\partial \ln C / \partial \ln qe$) has been computed from the estimated equations. Table 4 shows that for a one percent reduction in qe, there is a 0.5 percent increase in primary cost of abatement and a 0.4 percent increase in total costs of abatement.

[11] In the cost function literature, the elasticity of cost with respect to output is called cost flexibility. The elasticities of C with respect to V and qe computed here are akin to the concept of cost flexibility, since V and qe are connected with the output of abatement activity.

8. Average and Marginal Costs of Treatment

The estimated cost functions for primary treatment and total abatement (without CETP) can be used to derive the average costs and marginal costs of water pollution abatement, thus providing important policy implications for regulation of industrial water pollution in the case of small-scale factories. The full translog specification has been used to estimate the cost of abatement per kilolitre of wastewater treated, keeping input prices, qi and qe at their mean values and varying the quantity of wastewater. Table 5 and Graph 5-1 show the average costs of treatment with respect to quantity of wastewater.

Table 5

Quantityof wastewater (Kilolitres per annum)	**A** Average Cost of Treatment (Rs per kilolitre)	**B** Average Cost of Treatment (Rs per kilolitre)
900	370	516
1200	310	428
1500	260	369
1800	230	328
2100	210	296
2400	190	272
2700	180	251
3000	170	235
3300	160	220
3600	150	208
3900	140	198
4200	130	188
4500	130	180
4800	120	172
5100	120	166
5400	110	160
5700	110	154
6000	110	149

Note A : Based on primary treatment cost function
B : Based on total treatment cost function

Graph 5-1

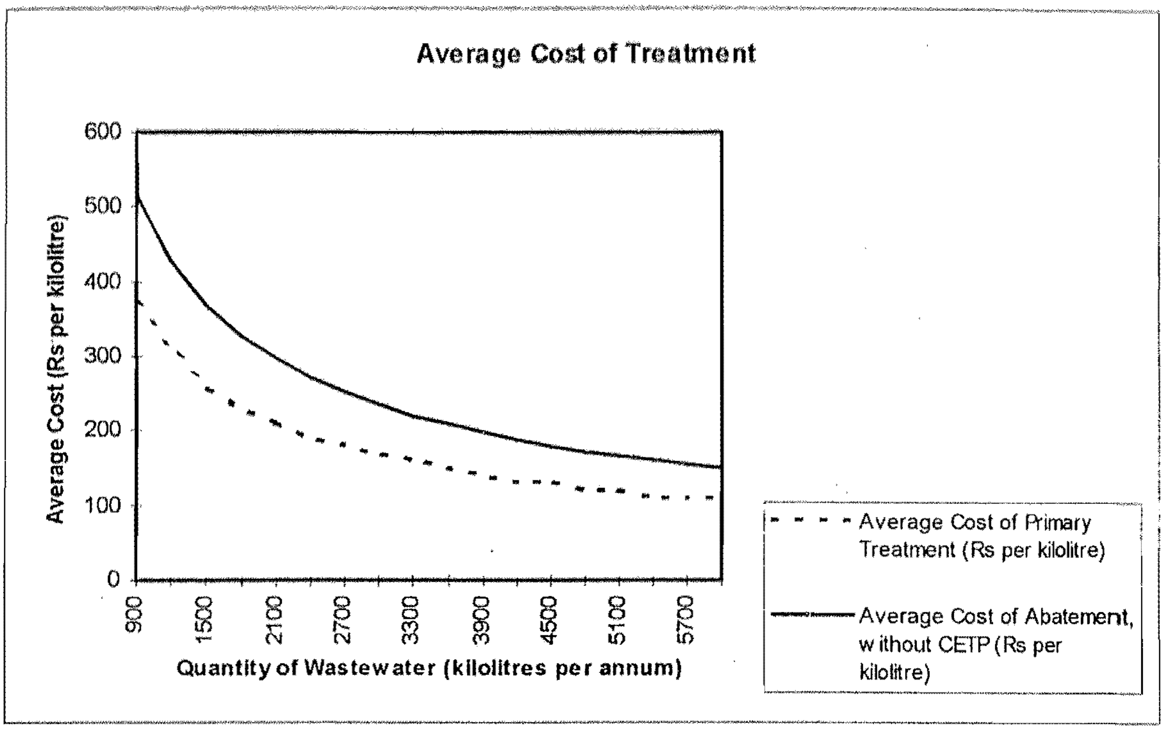


Table 5 and Graph 5-1 clearly show that the average cost of treatment falls sharply as the volume of wastewater treated increases, both for primary treatment and total abatement without CETP. Average cost for primary treatment is very high at Rs 370 per kilolitre when the quantity of wastewater treated is only 900 kilolitres. Due to economies of scale, the average cost falls sharply as the volume treated goes up. At the level of 6000 kilolitres of wastewater, the average cost is Rs 110 per kilolitre[12]. This shows that a small factory at a level of 6000 kilolitres of wastewater will have a much lower burden of water pollution abatement cost compared to a factory at the level of 900 kilolitres. The respective cost burden is much higher for the total cost of abatement. Hence smaller factories will have a greater cost advantage to join CETP for internalizing the externalities.

[12] The Goldar-Pandey (1997) study finds that abatement cost of wastewater treatment in distilleries (where the average per day wastewater volume is much larger), is in the range of Rs 20-30 per kilolitre. One must bear in mind that the nature of effluents is very different and simple cost comparisons between two studies cannot be made.

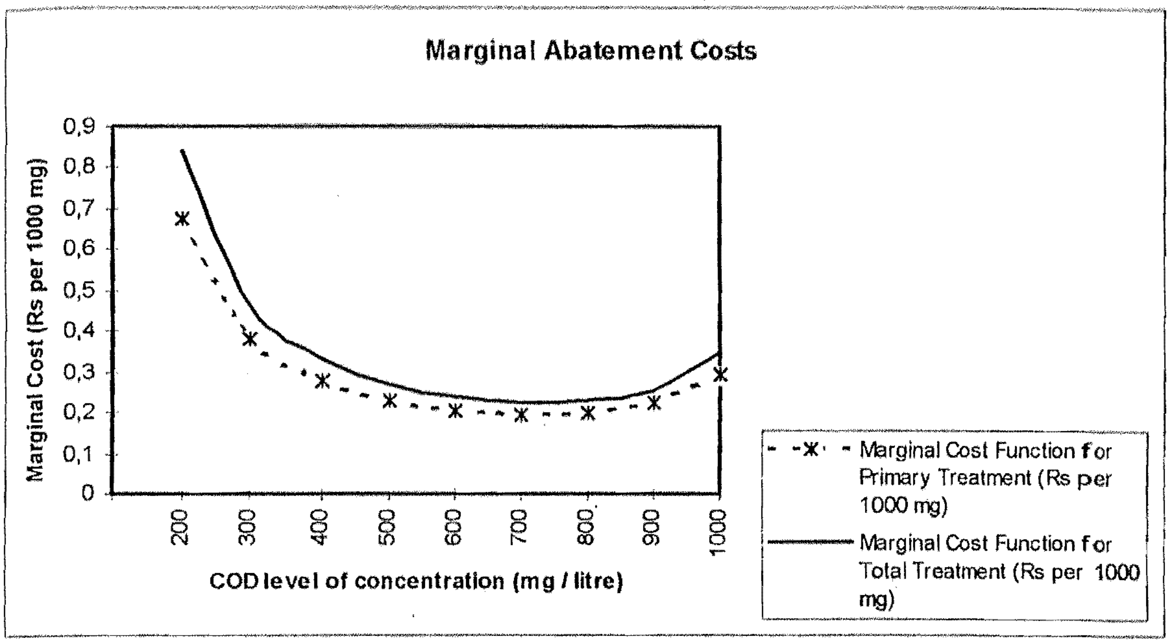
The full translog specification has been used to estimate the marginal cost of treatment. For these computations, input prices, V and qi are kept at their mean values; qe and hence the pollution load of COD effluent are varied. The pollution load is the product of COD effluent concentration and the volume of wastewater. Table 6 and Graph 6-1 show the marginal cost of abatement per unit of pollution load. The graph shows an inverse relationship between marginal cost and the COD effluent concentration. It is seen that at COD concentration level of 600 mg/litre, the marginal abatement cost is Rs 0.2 per gram of COD load. At COD concentration level of 200 mg/litre, the marginal abatement cost is Rs 0.7 per gram of COD load (higher in the estimate based on total abatement cost function).

Table 6

COD Effluent (mg/litre)	Marginal Cost (Rs per 1000 mg)	
	A	B
200	0.7	0.8
300	0.4	0.5
400	0.3	0.3
500	0.2	0.3
600	0.2	0.2
700	0.2	0.2
800	0.2	0.2
900	0.2	0.3
1000	0.3	0.3

Note A : Based on primary treatment cost function
B : Based on total treatment cost function

Graph 6-1



From Table 6 it can be seen that a water pollution tax on factories necessary for bringing about a complete abatement (SPCB requirements of COD = 250 mg per litre) should be around Rs 0.65 per gram of COD[13]. This is a very high rate of tax for internalizing the water pollution externalities to small-scale factories and clearly shows why such an instrument cannot be used.

9. Costs of Abatement under Alternate Institutional Arrangements

Having estimated the costs of water pollution abatement, it is necessary to determine the institutional arrangements which will efficiently internalize the externalities for the cluster of small-scale factories at Nandesari. This study compares the costs of

[13] According to James-Murty paper, the tax liability should be Rs 0.32 per 100 grams of COD in the case of large firms. Goldar-Pandey (1997) paper finds that at a tax rate of Rs 30 per 100 grams of BOD, the distillery will bring down the BOD concentration level to 30 mg/litre which is the present specified standard. One must bear in mind that the nature of effluents is very different and simple cost comparisons between two studies cannot be made.

abatement under (a) command and control regime, (b) market based solutions and (c) CETP arrangements.

(a) Command and Control Regime

Threats of closure of a polluting activity and penalties and imprisonment for the offending parties as envisaged in various legislations are `command and control' type of regulatory measures. It is widely known that command and control measures do not provide the necessary incentives to the polluters for the choice of least cost methods of pollution control (Cropper and Oates, 1992).

The cost of water pollution abatement for Nandesari Industrial Estate has been computed for a command and control regime. The estimated equation of total cost of abatement (without CETP) was used to find the actual costs for each factory to meet the SPCB requirement of COD = 250 mg/litre and the cost for the entire industrial estate was estimated. The cost of water pollution abatement under a command and control regime (without a CETP) works out to Rs 419 million. It reduces to Rs 331 million if the SPCB requirement relaxes to COD = 500 mg/litre. The command and control institution of abatement is highly inefficient because the factories are all abating to the same extent (SPCB requirements) but their marginal costs differ due to differences in size, pre-treatment level of pollution concentration etc.

(b) Market Based Solution

An efficient solution would arise if factories are allowed to trade the extent of water pollution abatement among themselves (meeting the SPCB standards for the entire industrial estate) and are not required to abate to the same extent individually. Such a solution could be brought about with the use of economic instruments (marketable pollution permits are used in USA) which in this study we shall call the `market based solution'. A `market based solution' cost of water pollution abatement has been obtained using a cost minimization model for this study. The total cost of water pollution abatement and water pollution load for the nth factory can be defined as follows:

$$TC(n) = f\,(V(n),\ dci(n),\ qe(n),\ pl(n),\ pk(n),\ pme(n)),$$

$$LD(n) = V(n) * qe(n),$$

$$\text{and } \sum_{n=1}^{38} LD\,(n) = LD$$

where $TC(n)$ = total cost of water pollution abatement for nth factory,

$pl(n)$ = price of labour for nth factory,

$pk(n)$ = price of capital for nth factory,

$pme(n)$ = price index of materials and energy for nth factory,

$dci(n)$ = $qi(n) - qe(n)$ = difference between the influent and effluent concentration of the COD pollutant for nth factory,

$qe(n)$ = effluent concentration of COD pollutant for nth factory,

$V(n)$ = quantity of wastewater used for treatment in nth factory,

$LD(n)$ = water pollution load for nth factory,

LD = total water pollution load for the sample factories.

The cost minimization model is as follows:

$$\text{Minimize } Z = \sum_{n=1}^{38} TC(n)$$

subject to

$$\sum_{n=1}^{38} LD\,(n) = LD \leq LD^*$$ (which is some targeted level of water pollution load to be achieved).

and $qe(n) \geq 0$.

Choice variables are $qe(n)$ for $n = 1, \ldots 38$.

Since TC(n) is a non-linear function of qe(n), we get a non-linear programming problem[14]. LD* has been specified at two levels, for COD at 250 mg/litre and COD at 500 mg/litre. Having thus obtained qe(n), the corresponding cost of water pollution abatement for each factory and for the entire industrial estate has been estimated using the translog cost function.

For a requirement of COD = 250 mg/litre, the least cost market solution generated a water pollution abatement cost of Rs 382 million i.e there is a saving of about Rs 37 million annually (or about 10 percent efficiency gains over command and control regime). The implication of this exercise is interesting because *each* factory need not abate to the level COD = 250 mg/litre. The *overall water pollution load* of Nandesari Industrial Area will meet the SPCB requirements of COD = 250 mg /litre. This is analogous to the market permit system already well established in USA. For a requirement of COD = 500 mg/litre, the least cost market based solution generated an abatement cost of Rs 260 million. In this case, the cost saving was even greater.

(c) Common Effluent Treatment Plant

As an alternative to the two institutional set-ups considered above, this study estimates water pollution abatement cost under a third institutional arrangement which is actually operating in Nandesari, namely a two step set-up based on primary treatment and a joint abatement at the CETP. In order to estimate the full cost of water pollution abatement (i.e. primary + CETP), the annualized cost of CETP is added to the annual primary treatment cost. This is the joint cost of water pollution abatement as a result of the institution of collective action (Misra 1995).

The capital cost of the CETP at 1996 prices is Rs 37.3 millions. Taking 18 percent as the opportunity cost and 10 percent as depreciation, the annualized value of the CETP capital cost is Rs10.4 million. The operations and maintenance cost is reported as Rs 1

[14] Excel Solver (programme) has been used for generating qe(n) for the sample factories.

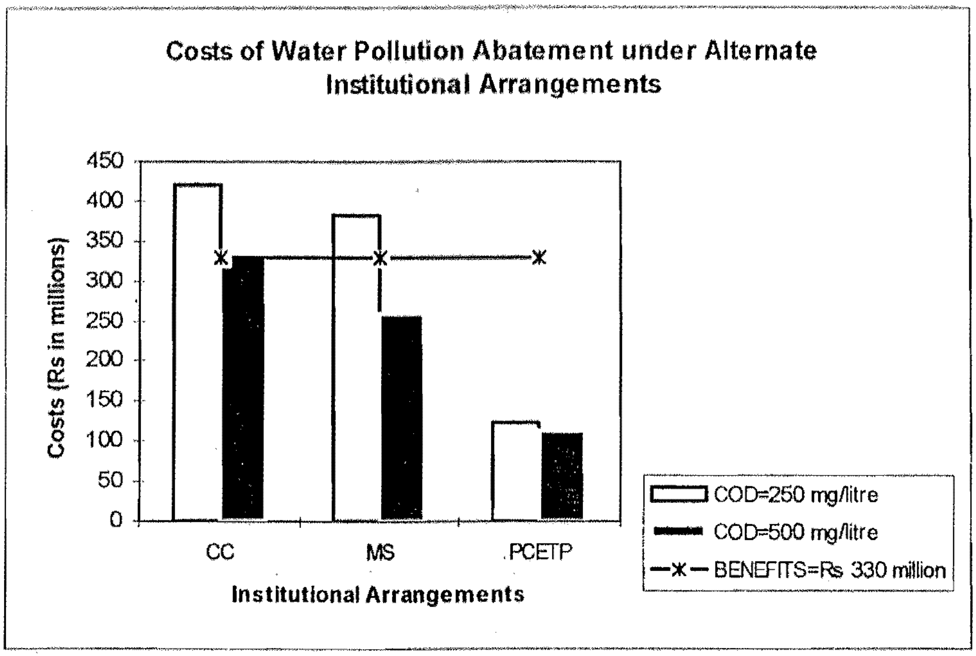
million per month. Thus the total CETP cost per annum is Rs 22.4 million. The total primary treatment cost incurred by the Nandesari Industrial Estate is estimated as Rs 100 million using the primary treatment cost function. Hence the total cost of water pollution abatement (i.e. primary +CETP) is Rs 122 million to meet the SPCB requirement of 250 mg/litre. This is the most efficient institution for water pollution abatement as can be seen from the bar diagram below. The cost reduces to Rs 114 million if the SPCB relaxes the statutory requirement to COD= 500 mg/litre.

Table 7 and Graph 7-a show the relationship between the three institutional arrangements, CC (Command and Control), MS (Market Based Solution) and PCETP (Primary with CETP). The institutional arrangement of the PCETP is most economical. The user and nonuser benefits estimated for six villages and the urban city of Vadodara have been estimated as Rs 330 million (Misra 1997) using the contingent valuation method. Graph 7-a shows large potential benefits can be generated using a CETP for water pollution abatement at Nandesari Industrial Estate. This study shows that collective action and a joint abatement is the ideal solution for internalizing the water pollution externalities to small-scale factories.

Table 7

Rs (millions)	Institutional Arrangements		
	CC	MS	PCETP
COD=250 mg/litre	419	382	122
COD=500mg/litre	331	260	114
BENEFITS=Rs 330 million	330	330	330

Graph 7-a



10. Conclusions

There has been no economic analysis of water pollution control decisions affecting operation and regulation of *small-scale* factories and this study is an attempt to bridge this gap, providing empirical evidence on costs of meeting standards for a cluster of 250 small-scale factories in Nandesari Industrial Estate of Gujarat in India. There have been several studies estimating the cost of pollution abatement for large industries. But there are serious inadequacies in the methodologies and problems of interpretation in these studies. While correcting for these inadequacies, this study estimates the costs related to water pollution abatement activity. The production of the abatement plant is viewed as a *service activity* or work done to reduce the level of pollution. The output of the abatement plant is the extent of pollution reduction achieved for each pollutant for a given volume of wastewater treated. Hence, the cost function used in this study has been derived from the related production activity.

The water pollution abatement activity at Nandesari is interesting since the abatement takes place at two stages. There is a primary treatment plant at the factory level to reduce the COD concentration level in the wastewater discharges. A secondary water pollution abatement takes place at the Common Effluent Treatment Plant mainly treating the joint effluents for BOD and COD concentrations to meet the standards of the State Pollution Control Board. The other important objective is to make an estimate of the cost of water pollution abatement to these small-scale factories in the absence of the CETP arrangements. For this purpose, the factory owners were asked to give details of the additional costs they would bear for a total abatement at the factory level. Using data collected from a sample of factories, this study estimates the costs of total abatement (in the absence of a CETP) in addition to the costs of primary treatment (with CETP).

The likelihood ratio test strongly rejected the Cobb-Douglas and truncated translog specifications in favour of the full translog specification of the cost function. Hence a full translog specification has been used to estimate the cost function. The present study is an improvement over the earlier studies in which the translog form could not be used for various reasons. The translog function results show that labour, capital and materials-energy are substitutes as the elasticities of substitution are positive for them. However, since price elasticities are low, the substitution possibilities between the inputs are limited for both primary treatment and total abatement.

This study provides empirical evidence of economies of scale in water pollution abatement activity. The results show that the average cost of treatment falls sharply as the volume of wastewater treated increases, both for primary treatment and total abatement (without CETP). Average cost for primary treatment is very high at Rs 370 per kilolitre for 900 kilolitres of wastewater treated. The average cost is Rs 110 per kilolitre for 6000 kilolitres of wastewater treated. This shows that the burden of water pollution abatement is higher for a smaller factory compared to a bigger one. The respective cost burden is much higher for the total cost of abatement. Hence smaller factories will have a greater cost advantage to join CETP. Also the results show an inverse relationship between marginal cost and the COD effluent concentration. A water pollution tax necessary for bringing about total abatement inorder to meet the SPCB requirement (COD = 250 mg per litre) should be around Rs 0.65 per gram of COD which is very high and clearly shows that this instrument will not work in the case of small-scale factories.

Alternate institutional arrangements have been considered for water pollution abatement activity at Nandesari. This study considers command and control, market based solutions and common effluent treatment as alternative scenarios. The costs of meeting SPCB standards is Rs 419 million for command and control regime; Rs 382 million for a market based solution and Rs 122 million for primary and common effluent treatment. The market solution cannot take advantage of a common treatment and hence is not as economical as the CETP arrangement. The potential benefits from water pollution abatement activities at Nandesari Industrial Estate have been estimated as Rs 330 million in an earlier study (Misra, 1997) for six villages surrounding Nandesari and the urban city of Vadodara, using the contingent valuation method. This study clearly shows that the institutional arrangement of the CETP is necessary to internalize the water pollution externalities in the case of small-scale factories and that large potential welfare gains can be generated.

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