Designing of Pigouvian Tax For Pollution Abatement in Sugar Industry

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1. Introduction

Many economists view the environmental pollution as a negative externality, which is an important source of 'market failure'. Existence of external costs have often led the policy makers to think entirely in terms of direct regulation. However, there is ample literature to suggest that direct regulation schemes, have not proved very effective means of controlling environmental pollution due to certain inherent defects in them. Some of the more important ones are; (i) control by means of regulation offers the polluter only the crudest form of economic incentive not to pollute the only exception being where fines imposed for violation exceed the cost of compliance[1], (ii) A strict application of the rule that each polluter must comply with the legislation results in large increases in abatement costs without producing any corresponding benefit to the environment[2], (iii) Where marginal costs of abatement, below the legislated pollution level, are less than the marginal gains that would accrue to society, a polluter has no economic incentive to make these efforts under a regulatory regime. Given these defects in direct regulation schemes, it is imperative to investigate how externalities may be reduced or eliminated through restructuring of poorly functioning market mechanism.

In principle the optimal level of pollution causing activity and the social costs of pollution are equalised at the margin. Alternatively, in a situation of an optimal use of the environment, the marginal pollution reduction costs are equal to the marginal environmental damage costs. However, in practice the above theoretical rule is difficult to use due to our limited knowledge of money value of most forms of pollution damage.

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[1] In most countries, especially developing countries including India the levels at which fines are set are too low to deter violators. Low levels of fine are generally accompanied by low probability of detection of violation which make the fines even less effective (see Theodore Panayotou, 1991 and R.W. Hahn 1989).

[2] See Baumol, W.J. and W.E. Oates (1971), Pearce, D.(1991), and Panayotou, T. (1991).

The literature therefore suggests a more workable approach to designing fiscal instruments that is to accept ambient emission standards as laid down by the environmental authorities and search for least cost methods of satisfying those standards.

Alternative approaches that approximate the working of a market for environmental resources have been suggested and used in various countries. Taxes and standards approach is one among the available approaches for internalization of externalities. This approach advocates that instead of relying on the market to set prices of environmental resources, the regulator may set price/charge for the same through legislation. If these charges are properly set they will lead to optimal use of environmental resources. Efficiency gains of taxes and standards approach over the direct regulation approachhave been documented in the literature (see Baumol, W.J. and W.E. Oates, 1971, and Eskeland, W.E. and E. Jimenez, 1992).

Ideally the system of setting charges is one based on ambient standards. This is done in two stages. First a target level of ambient quality (specified in terms of pollutants) is chosen. Then, the source standards for individual polluters (factories, municipalities, vehicles) are laid down taking into account the volume of pollution generating activities[3]. Once the source standards are laid the tax rate is fixed at a level where it is equal to the marginal cost of abatement at the allowable pollution level.

In India Water (Prevention and Control of Pollution) Cess Act which was introduced in 1977, it empowers the State Pollution Control Boards to levy a cess on local authorities supplying water to consumers and on consumption of water by specified industries. The Water Cess Act provides for a 25 per cent rebate on the cess payable if (i) the industry or local body concerned installs a effluent treatment plant and confirms to the pollution standards prescribed and (ii) industry does not consume water in excess of the quantity as may be prescribed for a specific industry.

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[3] In India while actual enforcement relates to source standards these are laid down independent of ambient standards.

The provisions of Water Cess Act and also the provision of rebate in water cess subject to compliance with the waste discharge and water use standards, indicate that the water cess is recognised potentially an important instrument for inducing both the conservation of water and pollution abatement.

Broadly water demanded by industries can be divided into two types of uses. One, for consumption and production and two, as a receptacle for waste/pollution. Since water cess is levied on water consumption and is not directly related to the quantities of effluent in the waste water it is structurally weak in influencing pollution abatement. Further, given the low rates of water cess, a rebate of 25 per cent is unlikely to have served as much of an incentive even for water conservation. However, in the absence of data on rebates it is difficult to verify this conjuncture. In fact, mixing of clean water to dilute the stream of waste water instead of treating the same is reported to be common practice among the polluting industries. Economically this makes sense as long as the cost of treatment for reducing pollutant concentration by units exceeds the cost of such quantities of water which would be required in achieving the equal reduction in pollution concentration.

The primary goal of this study is then to estimate the marginal abatement cost function. From the marginal abatement cost function, the tax rates necessary to achieve the given pollution standards are derived. The marginal abatement cost function has been estimated for water pollution abatement in Indian sugar industry.

In developing the marginal cost estimates, we have used a model of abatement cost which is discussed in Section 2. While Section 3 describes the marginal abatement cost Section 4 discusses the data. Methodology used to derive the marginal abatement cost is discussed in Section 5. In Section 6 we present our econometric results and the implied estimates of pollution abatement costs/tax.

2. TOTAL ABATEMENT COST

From an engineering perspective, abatement means installing and operating processes which reduce influent concentrations to target effluent concentrations where influent is the waste water from production before treatment and effluent is the residual emitted after the treatment. However, besides installing effluent treatment plant (ETP) at the end of the main production process, pollution control processes can also be installed within the main production plant at various stages of production. Costs incurred in in-plant pollution abatement are not considered in this study primarily due to lack of data on such costs and also due to problems in measuring the level of pollution removal attributable to these costs. Hence, abatement cost refers to only end-of-pipe abatement implying that the abatement cost function is separate from the firm's production cost function.

The effluent treatment plant (ETP) can be considered as a production activity which has a production function as does any other production activity, relating the maximum output obtainable from a given set of inputs. Output of ETP can be considered to be a product having two dimensions - the quantity and quality of effluent.

A production function for ETP can be specified as :

$$O = f(I,W) \qquad (1)$$

where :

O = vector of quantity (Q_E) and quality (q_E) characteristics of effluent ;

I = vector of quantity (Q_I) and quality (q_I) characteristics of influent ;

W = vector of various inputs such as capital, labour, energy and materials used for treatment.

For a cost minimising firm a cost function relating the effluent treatment cost to the level of treatment can be derived by minimizing costs ($c = \sum piwi$) subject to the production function. The cost function derived can be represented as

$$C = g(O,I,P) \qquad (2)$$

where :

$$O = Q_E \cdot q_E \qquad (3)$$

$$I = Q_I \cdot q_I \qquad (4)$$

P = represents the vector of factor input (capital, labour, energy and materials) prices; and q_I and q_E are concentration of pollutants per unit of Q_I(volume of influent) and Q_E(volume of effluent) respectively.

Substituting (3) & (4) into (2), we obtain,

$$C = g(Q_E.q_E \, , Q_I.q_I \, , P) \qquad (5)$$

It may be noted that though the cost function defined by (5) is a cost function derived as a dual to the production function, unlike the traditional cost functions, this has input (I) and not its price (due to non-priceable nature of I) as one of its arguments.

Using a specification similar to Cobb-Douglas the total cost function can be written as:

$$C = e^a \, (Q_I.q_I)^b \, (Q_E.q_E)^c \, P_L{}^d \, P_K{}^e \, P_E{}^f \, P_M{}^g \qquad (6)$$

$$b,d,e,f,g > o > c$$

where, C is the total cost of abatement, $Q_I.q_I$, $Q_E.q_E$ are pollution load in influent and effluent respectively. P_L, P_K, P_E and P_M are prices of labour, capital, energy and material respectively and e is the base of natural logarithm. Parameters to be estimated are a, b, c, d, e, f and g. The expected signs of b, d, e, f and g are positive. The sign of coefficient c is expected to be negative because increase in abatement or reduction in pollution in effluent leads to increase in cost of abatement (C).

It may be argued that since treatment activity in ETP refers to a process by which various components of the influent are removed/reduced or altered (in composition) such that the resulting product (effluent) is less damaging to the environment, the output of ETP is not the effluent coming out of ETP but the performance measure of ETP which can be considered to be the difference between the influent and effluent in terms of both quality and quantity. This can be specified as:

$$O = (Q_I.q_I) - (Q_E.q_E) \qquad (7)$$

on substituting (7) in (2) we get[4]

$$C = h\ \{(Q_I.q_I)-(Q_E.q_E),\ P\} \qquad (8)$$

This cost function suffers from two limitations.

First, since this specification takes the difference between q_I and q_E, it ignores the initial level of pollutants in influent which is an important determinant of abatement cost for a given reduction in pollutant concentration. Second, if we use Cobb-Douglas/translog functional form of the general cost function, another limitation surfaces. To see this, we write the total cost function similar to the Cobb-Douglas form with output as the only independent variable (ignoring other variables for the time being). This can be specified as:

$$C = \{(Q_I.q_I)-(Q_E.q_E)\}^b$$
$$b > o$$

Differentiating the above function with respect to pollution removal (R) gives

$$MC = \frac{dC}{dR} = b\{(Q_I.q_I)-(Q_E.q_E)\}^{b-1}$$

where R is the difference between the influent and effluent load.

Taking, Q_I, q_I and Q_E as fixed if we reduce effluent concentration (q_E), one would expect the marginal abatement cost to increase, implying $b > 1$. However, $b < 1$ would imply a decrease in marginal cost with an increase in abatement or decrease in q_E. Since, a priori, there is no reason to expect $b>1$ at all levels of abatement, the condition of $b>1$ comes as a limitation of this particular specification. A recent study (James and Murty 1996) apparently in order to get around this problem has used the ratio of influent and effluent concentration in the cost function. The cost function can be written as:

$$C = f\ (Q_I, q_I/q_E)$$

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[4] Since this specification of output (equation 7) has q_I, production function (equation 1) would then be $O = f(w)$ and corresponding cost function (equation 2) would be $C = h(O,P)$.

This cost function while takes care of the second limitation continues to suffer from the first limitation discussed above [in the case of cost function represented by equation (8)].

Another possible form of cost function can be given as below:

$$C = f\,\{Q_I,\ (q_I\text{-}q_E)/q_I\} \qquad (9)$$

Here, the right hand side variables represent volume of influent and reduction in pollutant concentration as a proportion of initial concentration respectively. This cost function while takes care of first limitation suffers from the second limitation outlined in the case of equation (8).

Given this, let us revert back to the cost function given by (6). In this function, input is influent load and output is effluent load. Though this specification overcomes the above limitations, the scale effect of change in volume of waste water on total cost is muddled between the input and output terms. In order to capture the returns to scale, volume of influent is included as a separate explanatory variable in equation (7). This is given as:

$$C = e^a\,(Q_I.q_I)^b\,(Q_E.q_E)^c\,P_L^d\ \ P_K^e\ \ P_E^f\ \ P_m^g\ \ Q_I^h \qquad (10)$$

$$b,\ d,\ e,\ f,\ g,\ h > o > c$$

The cost function given by (10) is close to the specification used by Mehta, Mundle and Sankar (1993) in that the three non-price variables, the principal determinants of the pollution abatement cost, enter the cost function separately. Their cost function is given as

$$C = f\,(Q_I,\ q_I,\ q_E) \qquad (11)$$

Since equation (6) is derived from minimizing cost subject to the production function it is an improvement over (11). Another advantage of (6) is that it theoretically provides for inclusion of volume of effluent (Q_E) into the cost functions which while has a bearing on the cost of abatement (under certain conditions[5]) can be used in making the existing legislation (Minimal National Standards) more efficient for pollution control. Further, treatment of sugar industry waste water consists of two stages; primary treatment and secondary treatment. While the cost of primary treatment principally depends upon the volume of waste water, the cost of secondary treatment is dependent upon the pollutants load. On this account also equation (6) appears to score over equation (11).

3. MARGINAL ABATEMENT COST

Until recently, the scarcity of appropriate plant-level data has prevented detailed empirical studies of marginal abatement cost, and this is especially true in the case of India. The only exceptions are recent studies by Mehta, Mundle and Sankar (1993) and James and Murty (1996). The 1993 study using an engineering cost function[6] estimated the marginal cost of BOD reduction using plant-level data of 22 paper and pulp firms. The study suggests that for setting of operational pollution charge, marginal cost estimates would have to be derived from data from a representative sample of firms. The study by James and Murty has estimated marginal abatement cost using plant level data of 82 firms drawn from 17 major polluting industries identified by the Central Pollution Control Board (CPCB) of India. While this study improves upon the sample size used by Mehta, Mundle and Sankar (1993), specification of its abatement cost function suffers from a serious limitation[7]. Further, since the study uses pooled data it ignores the differences in the nature of pollution problems faced and the variation in the cost incurred there-in by the various industries[8]. For instance, Hartman, Wheeler and Singh (1994) found considerable variation in marginal abatement costs by pollutant and sector. Sectoral abatement costs can be good guide for policy makers both in setting pollution charges and

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[5] Refer to Section 7.

[6] Refer to Section 2.

[7] Refer to Section 2.

[8] Some industries have wastes that are much more expensive to treat than are those of other industries. Also, pooled cost estimates will make sense only in the case of those industries, which have common pollution parameters.

in making a choice of sectors for greater focus for minimizing the social cost of abatement. In this paper an attempt is made to estimate such abatement costs by analysing plant-level data on costs of water pollution abatement in sugar industry.

The cost function defined by (10) provides means to calculate the marginal cost of pollution reduction over a range of pollution concentration for ETPs treating effluent streams of various flow sizes. The marginal cost, is the change in total cost at the margin arising from removing an additional unit of pollutant, i.e. the incremental cost in reducing the output(O) by one unit while holding the input(I) fixed. In brief, the change in total cost (C) at the margin arising from an unit change in $Q_I q_I - Q_E q_E$ is defined as marginal cost (MC).

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

where; $R = Q_I q_I - Q_E q_E$ (pollutant removed)

4. SAMPLE AND DATA

The term sugar is generally used for refined crystalline sugar obtained from sugar industry. In India, most sugar mills have a crushing capacity in the range of 1250 to 6000 tonnes per day excepting a few sugar mills which have higher crushing capacity of 7000 tonnes per day.

Engineering literature identifies four major factors which determine the cost of abatement: pollutant type, volume of influent, pollution concentration in the influent stream and the desired level of abatement. Costs vary widely according to waste stream characteristics and desired level of abatement. However, variations in volume and concentration of pollutants among firms even within an industry are due to differences in vintage of plant, production process, type of fuel and other inputs used and abatement technology.

There is very little variation in the production process of sugar, across the country. The main feedstock used in production of sugar is sugarcane. Sugarcane juice is extracted in the milling plant which is then heated and treated either by double sulphitation or double sulphitation with carbonation process. Double sulphitation is more commonly used. In carbonation process lime stone is used in treating sugarcane juice. This process improves whiteness and structure of sugar crystals. However, this process has recently been banned, the main reasons being low availability of lime stone and large amounts of sludge produced in using this process.

The pollution problem arising out of the plant operation for the manufacture of sugar is mostly confined to water pollution. The average effluent flow per tonne of cane crushed is as below:

Crushing Capacity tonnes per day	Effluent Generation Kl per day	Effluent Generation Kl per day per tonne of cane crushed
upto 1500	300-500	44 kl/tonne
1500-3000	800-1200	44 kl/tonne
3000-5000	1500-2000	42 kl/tonne
5000 and above	2500-3000	49 kl/tonne

Source: Comprehensive Industry Document series 1980-81, Central Pollution Control Board.

It can be seen from above that volume of effluent generated per tonne of sugarcane crushed does not vary significantly with the scale of production. The main factors causing variation in effluent generation per unit of sugarcane crushed are: management's attitude towards water conservation and poor maintenance.

Variation in pollution concentration in waste water is mainly attributed to age of the plant, quality of sugarcane used and lack of in - plant pollution control measures such as improper collection of lubricants and molasses which find their way into the drains carrying waste water.

The data used in this study is in respect of 53 firms. The data has been obtained from an Environment Engineering Consultant who has designed and commissioned ETP's in various sugar firms. Two considerations led us to obtain data from an engineering consultant. One, poor response of firms in providing the required data and two, the reliability of data. A similar observation is made in Mehta, Mundle and Sankar 1993, "since the polluting firms have no incentive to reveal the true costs of abatement they often provide only the accounting data. In such a situation data generated with the aid of designers of ETP's and scientists working in the area of pollution control can provide better estimates of the economic costs of abatement than the data obtained from firms".

5. MEASUREMENT & ESTIMATION :

The cost functions chosen for estimation are[9];

(A) $C = g(Q_I.q_I \, , Q_E.q_E \, , Q_I, P_L, P_K)$

This abatement cost function is also estimated dropping the price variables. This is done primarily to find out the variation in marginal abatement cost due to non-inclusion of price variables in the total cost function.

(B) $C = h \, \{Q_I, (q_I - q_E)/q_I, P_L, P_K\}$

This cost function is estimated to find out the coefficient value of $(Q_I.q_I - Q_E.q_E)$ (refer to Section 2, equation 9).

The Cobb-Douglas functional forms are used in estimating the above abatement cost functions. The cost functions are given as:

$$C = e^{a+b} (Q_I.q_I)^c (Q_E.q_E)^d Q_I^e P_L^f P_K^g e^u$$

$$c, e, f, g > o > d$$

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[9] Since there was no significant variation observed in the price of energy and material these have not been considered in the estimated equation.

and,

$$C = e^{a+b} Q_I^c \{(q_I-q_E)/q_I\}^d \; P_L^e \; P_K^f \; e^u$$

$$c, e, f>o$$

$$d>1$$

where;

C = Total cost of treatment

Q_I = Volume of influent

Q_E = Volume of effluent

q_I = Concentration of pollutants in Influent

q_E = Concentration of pollutants in effluent

P_L = Annual wages of Labour

P_K = Price of Capital

u = Error term

Total cost of treatment is taken as consisting of operating cost and a fixed cost. Fixed cost is measured as the annualised capital cost. Assuming a life of twenty years for the real capital and using the bank rate of interest as a proxy for investor's opportunity cost of capital, annualised capital cost is calculated. Price of labour is computed as the ratio of total emoluments to total employees. To compute the price of capital input we have followed the following method. The price of capital service is obtained as;

$$P_K = P_1(r+\delta)$$

Where P_1 is the ratio of capital expenditure on ETP to pollution load removed, r is the rate of return on capital and δ is the rate of depreciation. For the rate of return on capital we have taken the bank rate (as a proxy for the prime lending rate) while the rate of depreciation δ is computed assuming a life of twenty years of the ETP.

Pollution abatement in sugar industry primarily consists of treating waste water in order to bring the BOD, the COD, alkaline content and suspended solids within tolerance limits. While suspended solids and alkaline content are controlled in the primary treatment, biological treatment brings the COD and BOD down. Abatement of COD and

BOD is a joint process since a given process is used to control both the pollutants at the same time. However, in the case of sugar effluent the relationship between COD and BOD is such that BOD can safely be treated as the single parameter measure of pollution. This implies that the data on abatement cost used here relates to controlling the level of various pollutants for which standards are specified and enforced by the regulating agencies.

The final abatement cost functions of the Cobb-Douglas form for estimation are;

$$C = e^{a+b}.(Q_I.q_I)^c\ (Q_E.q_E)^{d.}\ Q_I^e\ P_L^f\ P_K^g\ e^u \qquad \text{(i)}$$

$$c,\ e,\ f,\ g > o > d$$

$$C = e^{a+b}\ (Q_I q_I)^c\ (Q_E q_E)^d\ Q_I^e\ e^u \qquad \text{(ii)}$$

$$c,\ e > o > d$$

$$C = e^{a+b}\ Q_I^c\ (q_I - q_E/q_I)^d\ P_L^e\ P_K^f\ e^u \qquad \text{(iii)}$$

$$c,\ e,\ f > o$$

$$d > 1$$

$$C = e^{a+b}\ Q_I\ (q_I - q_E)^c\ P_L^d\ P_k^e\ e^u \qquad \text{(iv)}$$

$$c > 1 \quad d,e > 0$$

Ordinary least squares is used for estimating the functions after transforming these into log linear forms.

Cost function (i) in translog form (as given by (v) below), is similarly estimated using OLS.

$$\begin{aligned}\ln C = {} & a + c\ln(Q_I.q_I) + d\ln(Q_E.q_E) + e(\ln Q_I) + f\ln(P_L) + g\ln(P_K) + \\ & h1/2[\ln(Q_I.q_I]^2 + i\ \ln(Q_I\ q_I)(\ln Q_E\ q_E) + j\ [\ln(Q_I\ q_I)\ \ln P_L] + k\ [\ln(Q_I\ q_I)\ \ln P_K] + \\ & l1/2[\ln(Q_E\ q_E)]^2 + m\ [\ln\ (Q_E\ q_E)\ \ln P_L] + n\ [\ln\ (Q_E\ q_E)\ \ln P_K] + O\ 1/2\ [\ln\ (Q_I)]^2 \\ & + P\ 1/2\ [\ln\ (P_L)]^2 + q\ [\ln\ (P_L)\ \ln\ (P_K)] + r\ 1/2\ [\ln P_K]^2 \qquad \text{(v)}\end{aligned}$$

In the absence of data on Q_E it is assumed that $Q_I = Q_E$.

6. Marginal Abatement Cost In Sugar Industry:

Results and Discussion

Regression results of the cost function represented by (i) to (iv) are presented in Table 1.

Table 1

Parameter Estimates of the Total Abatement Cost Functions

Dependent Variable: Ln (Total cost)

	Equations			
Explanatory Variable	(i)	(ii)	(iii)	(iv)
Ln (Q_I)	0.31742 (10.99)	0.38956 (13.687)	0.53466 (18.641)	-
Ln ($Q_I . q_I$)	0.47588 (9.4358)	0.39924 (14.487)	-	-
Ln ($Q_I . q_E$)	-0.65309 (-7.7904)	-0.43347 (-6.6690)	-	-
LnQ-I (q_I-q_E)	-	-	-	0.96479 (58.738)
Ln (q_I-q_E)/q_I	-	-	-0.18008 (-0.2994)	-
Ln (P_L)	0.11309 (4.6446)	-	0.16617 (4.1641)	0.10535 (8.2386)
Ln (P_K)	0.13634 (2.4402)	-	-0.3493 (-7.0859)	0.88238 (30.517)
Constant	-7.0724 (-17.402)	-5.617 (-27.721)	-3.56 (-10.966)	-11.749 (-78.041)
Adjusted R-square	0.9917	0.9866	0.9765	0.9973

Bracketed figures are t ratios

It can be seen from Table 1 that the coefficients of variable (q_I-q_E)/q_I and (q_I-q_E) Q_I in equations (iii) and (iv), respectively, have values less than 1 which as noted in Section 2 is not a desirable characteristic hence we reject these equations. Since Ramsey-

Reset test conducted to check for specification error suggests the presence of left out variables in the case of (ii), equation (i) is the obvious choice. Results of equation (i) are used in computing the marginal abatement cost.

Also, the full translog form of (i) and one of its truncated versions are estimated. Regression results of these are presented in Annexure 1. While results have improved in terms of fit, the coefficients are no longer so well behaved. Hence, these are not used for computing marginal abatement cost.

The marginal abatement cost equations are derived from the total abatement cost function. The marginal abatement cost estimates, obtained by using the Cobb-Douglas functional form, of removing 100 grams of BOD at various levels of BOD concentration in effluent for minimum, average and maximum levels of both q_I and Q_I are presented in Table 2. By plotting the estimated values of marginal cost (as given in Tables 2) marginal abatement cost curves are derived. The graphs (A1 to A3) show the marginal cost of BOD removal against various levels of BOD concentration remaining in the effluent, given an initial influent concentration. Changes in volume (Q_I) are represented by parametric shifts in the marginal cost function. Several observations can be made from these table and graphs.

Table 2

MARGINAL COST OF REMOVAL OF 100 GRAMS OF BOD : ESTIMATION

IIT data

q_E in mg/l*	q_I in mg/l								
	600(Minimum)			992.45(Average)			1200(Maximum)		
	Q_I in Kiloliters								
	500 (Minimum)	1335.8 (Average)	2500 (Maximum)	500 (Minimum)	1335.8 (Average)	2500 (Maximum)	500 (Minimum)	1335.8 (Average)	2500 (Maximum)
20	1.88	1.44	1.21	2.38	1.82	1.54	2.61	2.00	1.68
30	1.22	0.93	0.79	1.55	1.18	1.00	1.69	1.30	1.09
40	0.90	0.69	0.58	1.14	0.87	0.74	1.25	0.95	0.80
50	0.71	0.54	0.46	0.90	0.69	0.58	0.98	0.75	0.63
60	0.58	0.45	0.38	0.74	0.57	0.48	0.81	0.62	0.52
70	0.49	0.38	0.32	0.63	0.48	0.41	0.69	0.53	0.44
80	0.43	0.33	0.28	0.54	0.42	0.35	0.60	0.46	0.38
90	0.38	0.29	0.24	0.48	0.37	0.31	0.53	0.40	0.34
100	0.34	0.26	0.22	0.43	0.33	0.28	0.47	0.36	0.30
110	0.31	0.23	0.20	0.39	0.30	0.25	0.42	0.32	0.27
120	0.28	0.21	0.18	0.35	0.27	0.23	0.39	0.30	0.25
130	0.26	0.20	0.16	0.32	0.25	0.21	0.36	0.27	0.23
140	0.24	0.18	0.15	0.30	0.23	0.19	0.33	0.25	0.21
150	0.22	0.17	0.14	0.28	0.21	0.18	0.30	0.23	0.20
160	0.20	0.16	0.13	0.26	0.20	0.17	0.28	0.22	0.18
170	0.19	0.15	0.12	0.24	0.19	0.16	0.27	0.20	0.17
180	0.18	0.14	0.12	0.23	0.18	0.15	0.25	0.19	0.16
190	0.17	0.13	0.11	0.22	0.17	0.14	0.24	0.18	0.15
200	0.16	0.12	0.10	0.21	0.16	0.13	0.22	0.17	0.14

* MINAS for BOD in the case of sugar industry is 30 mg/l for disposal of effluent in surface water and 100 mg/l for disposal of effluent on land.

First, marginal abatement cost is seen to be rising, with the fall in the concentration of BOD in the effluent. In other words, the marginal cost curves (in A1 to A3) show an upward trend when plotted against decrease in concentration of pollutant or increase in abatement.

Second, initial reductions in BOD levels are achieved at relatively low resource cost. As the BOD level is brought down, further reductions can be achieved only at an increasing cost (marginal cost curve is rising very sharply). The marginal cost of 100 grams of BOD removal for an initial q_I level of 992.45 mg/l (sample average) and Q_I of 1335.8 KL (sample average) is Rs. 0.33 and Rs. 0.69 to achieve a q_E level of 100 mg/l and 50 mg/l respectively. But it is Rs. 1.18 for q_E = 30 mg/l (see Table 2). Costs rise very sharply once the BOD concentration has been brought down to 30 mg/litre.

Another important observation is the increasing returns to scale (here refers to the volume of water treated). With a rise in the volume of waste water entering into the ETP, other things remaining constant, the same removal in terms of BOD concentration can be achieved at a lower cost. Beginning with q_I=992.45 mg/l, to achieve a q-E of 200 mg/l , marginal abatement cost of removal of 100 grams of BOD is Rs. 0.13 and Rs. 0.21 corresponding to the influent volumes of 2500KL and 500KL respectively as compared to Rs. 0.16 for Q_I of 1335.8 KL. To bring down q_E to 50 mg/l from 200 mg/l increment to marginal abatement cost is lower at around Rs. 0.45 (for Q_I = 2500) as against Rs. 0.53 (for Q_I = 1335.8).

Finally, marginal abatement costs are also substantially higher with equation (i) than marginal cost estimates obtained from equation (ii). This suggests that the abatement cost estimates based on engineering cost functions need to be taken with caution.

7. Marginal Abatement Cost and Pollution Taxes

The purpose of our analysis is to devise a pollution tax, aimed towards a cleaner environment. Before discussing the rate and its implications, we would like to draw attention towards another aspect of pollution control measure, namely, laying down of the minimal national standards (MINAS).

In India, MINAS is defined as the maximum concentration of pollutants permissible in a given quantity of water. There is no regulation on the volume of waste water discharged by factories. Hence, only the concentration of pollutants in the water finally disposed from the factories is monitored with no check on the volume of waste water.

I. Addition of Clean Water: A Case For Redefining MINAS

In the absence of any restriction on the volume of waste water, mixing clean water to dilute the stream of waste water instead of treating the same is a possibility. This would be done as long as the cost of treatment for reducing the pollution concentration by x units exceeds the cost of such quantities of water which would be required in achieving the equal reduction in pollution concentration. In such a scenario the objective of natural resource conservation would be defeated with the legislation allowing the firms to resort to further pollution in order to combat the present pollution load.

Unfortunately, without appropriate data on the volume of effluent emerging from the ETP (Q_E of our model) we have no means of empirically verifying this contention. Instead, based on the available data we explore the substitution possibilities of treatment by dilution.

Addition of clean water to the influent, before its treatment in the ETP, has two effects; the volume of influent (Q_I) goes up and the concentration of pollutants in influent goes down. The first effect impinges an additional cost on the producer to the extent that the producer has to treat a much greater effluent stream. However, a higher Q_I also enables the producer to take advantage of the increasing returns to scale (as shown above). The second effect i.e. a reduced concentration of BOD in the influent works towards lowering the cost of treatment. This is because with dilution a relatively lower level of treatment would be required to achieve a given level of pollutants concentration in effluent.

Thus, we can hypothesize that, the possibility of addition of clean water to the influent, in order to reduce the BOD concentration and thereby reduce the marginal cost of treatment is very strong. If the producers have access to cheap water sources they will certainly exploit the possibility of substituting the clean-up cost by clean water until marginal saving in cost of treatment equals the cost (volume used x marginal price) of water.

Estimates of total abatement cost and marginal savings in total cost of abatement due to addition of clean water in influent are presented in Table 3. The estimates of total abatement cost show that addition of clean water in influent has the effect of reducing the total cost of abatement. Column 1 of Table 3 gives the changes in the volume of influent, as 100 kiloliters of water is added each time. The resulting decline in the concentration of influent is given in column 2. Total cost is, then, recalculated for $q_E =$ 30 mg/l (see column 4). The marginal saving in total abatement cost on dilution is given in column 5.

TABLE 3

Reduction in Abatement Cost on Dilution of Influent

S.No.	Q_I (1)	q_I (2)	q_E (3)	Total Cost of Abatement Rs. (4)	Marginal Saving in Total Cost Rs. (5)
1	671.73	950	30	12262.59	-
2	771.73	826.90	30	12151.27	111.32
3	871.73	732.04	30	12054.37	96.90
4	971.73	656.71	30	11968.66	85.71
5	1071.73	595.43	30	11891.87	76.79
6	1171.73	544.62	30	11822.36	69.50
7	1271.73	501.79	30	11758.91	63.45
8	1371.73	465.21	30	11700.57	58.34
9	1471.73	433.60	30	11646.60	53.98
10	1571.73	406.01	30	11596.40	50.20
11	1671.73	381.73	30	11549.49	46.91
12	1771.73	360.18	30	11505.48	44.01
13	1871.73	340.94	30	11464.05	41.44
14	1971.73	323.65	30	11424.90	39.14
15	2071.73	308.02	30	11387.82	37.08
16	2171.73	293.84	30	11352.60	35.22
17	2271.73	280.91	30	11319.07	33.53
18	2371.73	269.86	30	11287.08	32.00

It may be seen that with the addition of 500 kiloliters of clean water, the total abatement cost shows a decline from Rs. 12262.59 to Rs. 11822.36 i.e., by 3.6 percent. The initial reductions in total abatement cost are relatively high in magnitude. These gradually diminish with successive additions of clean water (see Column 5, Table 7). Equilibrium, the point till which the firms find it profitable to dilute the waste water rather than treat the same, is attained when marginal savings in total abatement cost would equal marginal cost of clean water. In the absence of information on marginal cost of water the average cost of water[10] is used to analyze the possibilities of dilution with clean water. If the case put up in Table 7 for illustration is the case in point the firm's equilibrium point will be one at which marginal saving in total abatement cost is Rs.68 (which occurs after addition of 550 KL (approx) of clean water).

The above exercise highlights one of the major loopholes present in the present legislation and underlines the immediate need to redefine MINAS in terms of pollution load. The total amount of pollutant (concentration multiplied by volume) disposed into the water bodies should be monitored rather than only the concentration. Thus if BOD is taken as the index of pollutants in waste water - its concentration measured in milligrams per liter of water and the total volume of water disposed in liters or kiloliters - then **MINAS should be expressed in terms of milligrams or grams rather than milligrams per liter.**

Since pollution load would vary from industry to industry, depending upon its nature of production, and from firm to firm, depending upon its scale of production, this would involve laying down of separate firm & industry specific standards. One way out of this problem, is to define MINAS as a ratio of the pollution load emitted to the total turnover or output. Such a measure will help in checking the wastage of valuable water resources, conservation of which is our primary aim.

This would, in a way, imply that the water demand management be done through quantity restrictions which does not fall in line with the use of economic incentive instruments for resource management and environmental protection. Also, load based standards would involve a wide network of administrative machinery and hence considerable administrative expenses, as the monitoring requirements would be much higher in this case. Is there an alternative?

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[10] Average cost of 1 kl of water is taken at Rs. 0.68. See Ramesh Bhatia and others (unpublished) and Gupta, Murty and Pandey, 1989.

Price of water in India often does not cover the cost of delivery, let alone its opportunity cost or scarcity value. This results in over use/wasteful use of water. Broadly water demanded by industries can be categorised into two types of uses. One, for consumption and production and two, as a receptacle for waste/pollution. The water user should therefore pay fully for the cost of delivery, depletion and pollution. While pollution tax suggested in the following section can take care of the cost of pollution, price of water should include the cost of delivery and depletion. In a scenario where demand for water is influenced through its price, existing MINAS will hold.

II. Rate of Pollution Tax

It may be noted from Table 2 that marginal costs for a given q_E vary across influent pollution levels and influent volumes. Hence, the question is which level of marginal cost be used as a basis for setting pollution taxes. Clearly, the tax rate should be set equal to the highest marginal cost of abatement[11]. This would encourage the firms with low marginal cost of abatement to abate as they would find it profitable to do so rather than pollute. Such a tax would also ensure that the regulatory authority recovers the cost of clean up from the violators.

We know that since there are economies with respect to both influent volume and also that marginal cost of abatement to MINAS level is higher when the influent concentration is higher, the marginal cost of abatement for a given q_E(say MINAS level) would be highest for the firm with lowest volume and highest influent concentration. It is suggested therefore that the cost of abatement of the smallest unit in terms of volume and highest unit in terms of influent pollution concentration be taken as the benchmark for setting pollution taxes for sugar industry. We therefore consider the lowest Q_I (500 kl) and the highest q_I (1200 mg/l) as benchmark for setting pollution tax. On this basis the tax rate works out to Rs. 1.69 per 100 gram of BOD at 1993-94 prices for $q_E = 30$ mg/l (MINAS for disposal in surface waters). This would be levied on per 100 gram of extra

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[11] Though it would be more appropriate to leave the outliers (in terms of very low Q_I and very high q_I) if these can be identified.

BOD beyond MINAS.

The suggested pollution tax rate is higher in comparison to pollution tax rates suggested by Mehta, Mundle and Sankar (1993), and James and Murty (1996). This may be attributed mainly to two factors specific to sugar industry. One, low demand for water per unit of sugar vis-a-vis paper or fertilizers. This can be explained with the help of following example. Let us consider two industries, A and B. Let's say that representative firms of industry A and B discharge 10 grams of BOD each per unit of output and their water requirements per unit of output are 10 and 15 units respectively. Given these influent BOD concentration (mg/l) of firm in industry A would be higher than that of the firm in industry B. Since MINAS is defined and enforced in terms of pollutant concentration (mg/l), abatement requirement of the firm in industry A would be higher than that of the firm in industry B. Besides, the firm in industry B takes the advantage of economies of scale in pollution abatement. Two, sugar industry is seasonal operating on an average for about 150 days during a year - which implies higher capital costs as well as maintenance costs per unit of pollution reduction vis-a-vis industries working throughout the year.

Conclusion

The analysis in this paper, in the case of firms in sugar industry, demonstrates a theoretically sound methodology of determining a set of tax rates to effectively enforce the existing source standards for water quality. Such an analysis can be extended to other polluting industries. The analysis points out the loophole in the existing legislation (MINAS) and suggests that the pricing of water be rationalised. Further, pollution tax would require periodic revisions based on considerations such as firms' response, inflation, advent of new technology (changes in firm's production function). Also, as pollution causing activity rises and source specific standards are made more stringent in order to maintain the same ambient standards, pollution tax will have to be revised from time to time.

Annexure 1

Parameter Estimates of Translog Cost Function

Dependent Variable: Ln (Total Cost)

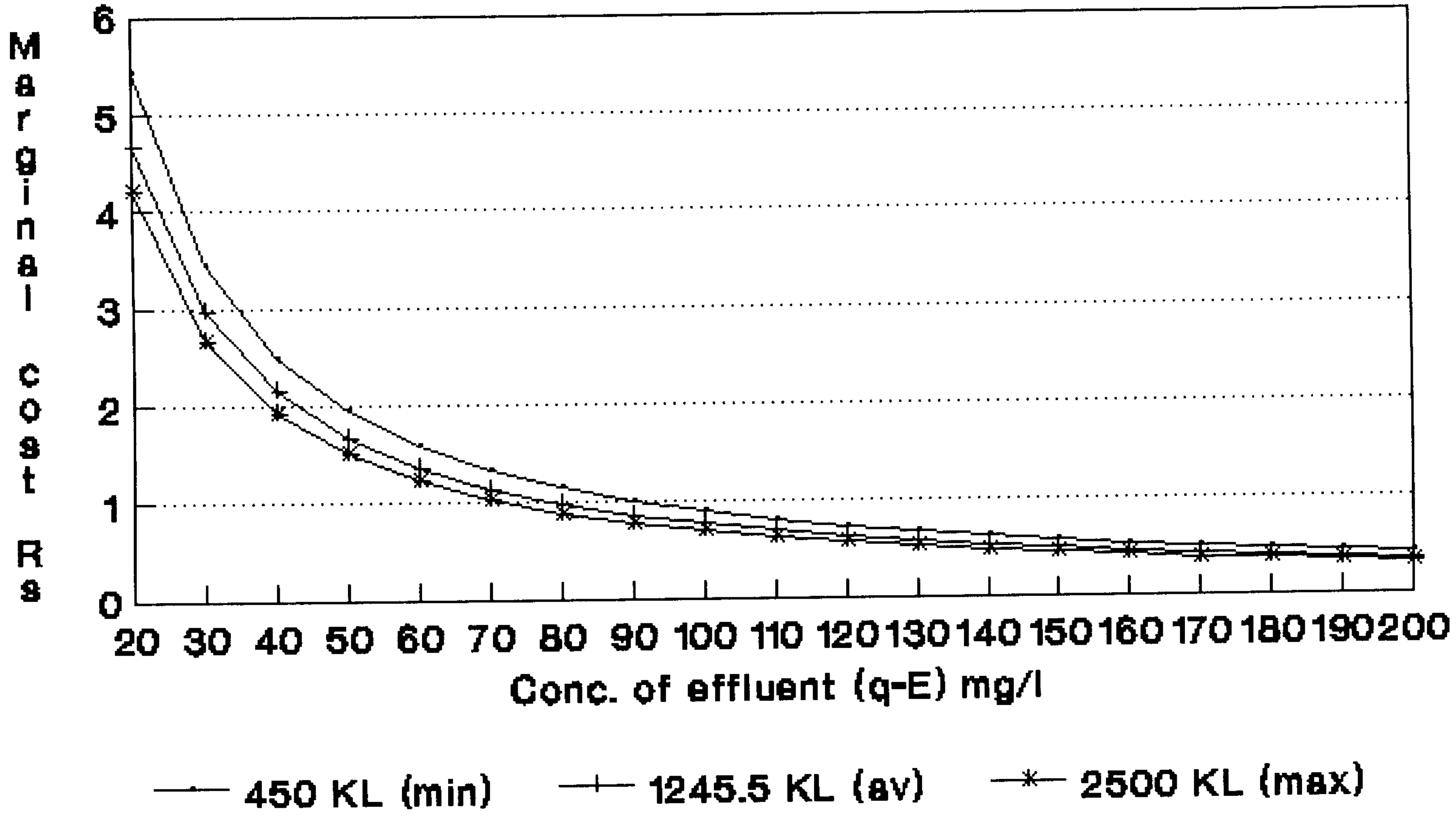
No. of Observations: 67

EXPLANATORY VARIABLE	Equation	
	(i)	(ii)
$Ln(Q_I)$	-0.93787 (-1.72)	-
$Ln(Q_Iq_I)$	7.155 (3.68)	7.5853 (4.82)
$Ln(Q_Iq_E)$	0.10002 (0.24)	(0.02) 0.047887
$Ln(P_L)$	0.26398 (0.17)	-2.2015 (-1.57)
$Ln(P_K)$	8.9007 (3.95)	9.838 (5.03)
$0.5\{Ln(Q_Iq_I)\}^2$	-0.50155 (-2.58)	-0.65529 (-4.25)
$\{Ln(Q_Iq_I).Ln(Q_Iq_E)\}$	0.078282 (1.75)	0.13424 (3.64)
$\{Ln(Q_Iq_I)Ln(P_L)\}$	-0.043223 (-0.35)	0.059337 (0.47)
$\{Ln(Q_Iq_I)Ln(P_K)\}$	-0.42819 (-2.34)	-0.58021 (-3.96)
$0.5\{Ln(Q_Iq_E)\}^2$	-0.062269 (-2.20)	-0.092174 (-3.83)
$\{Ln(Q_Iq_E)Ln(P_L)\}$	-0.058472 (-1.71)	-0.091217 (-2.64)
$\{Ln(Q_Iq_E)Ln(P_K)\}$	-0.10352 (-2.60)	-0.085702 (-2.08)
$0.5\{Ln(P_L)\}^2$	0.095671 (0.64)	0.23255 (1.52)
$\{Ln(P_L)Ln(P_K)\}$	-0.13359 (-1.44)	-0.43404 (-0.35)
$0.5\{Ln(P_K)\}^2$	-0.48292 (-2.19)	-0.68201 (-3.82)
$0.5\{Ln(Q_I)\}^2$	0.14957 (1.93)	-
Dummy Variable	0.2421 (7.21)	0.2464 (6.84)
Constant	-49.884 (-4.00)	-42.647 (-3.68)
Adjusted R-square	0.9804	0.9774

MARGINAL COST OF ABATEMENT

for different flow size (Q-I)

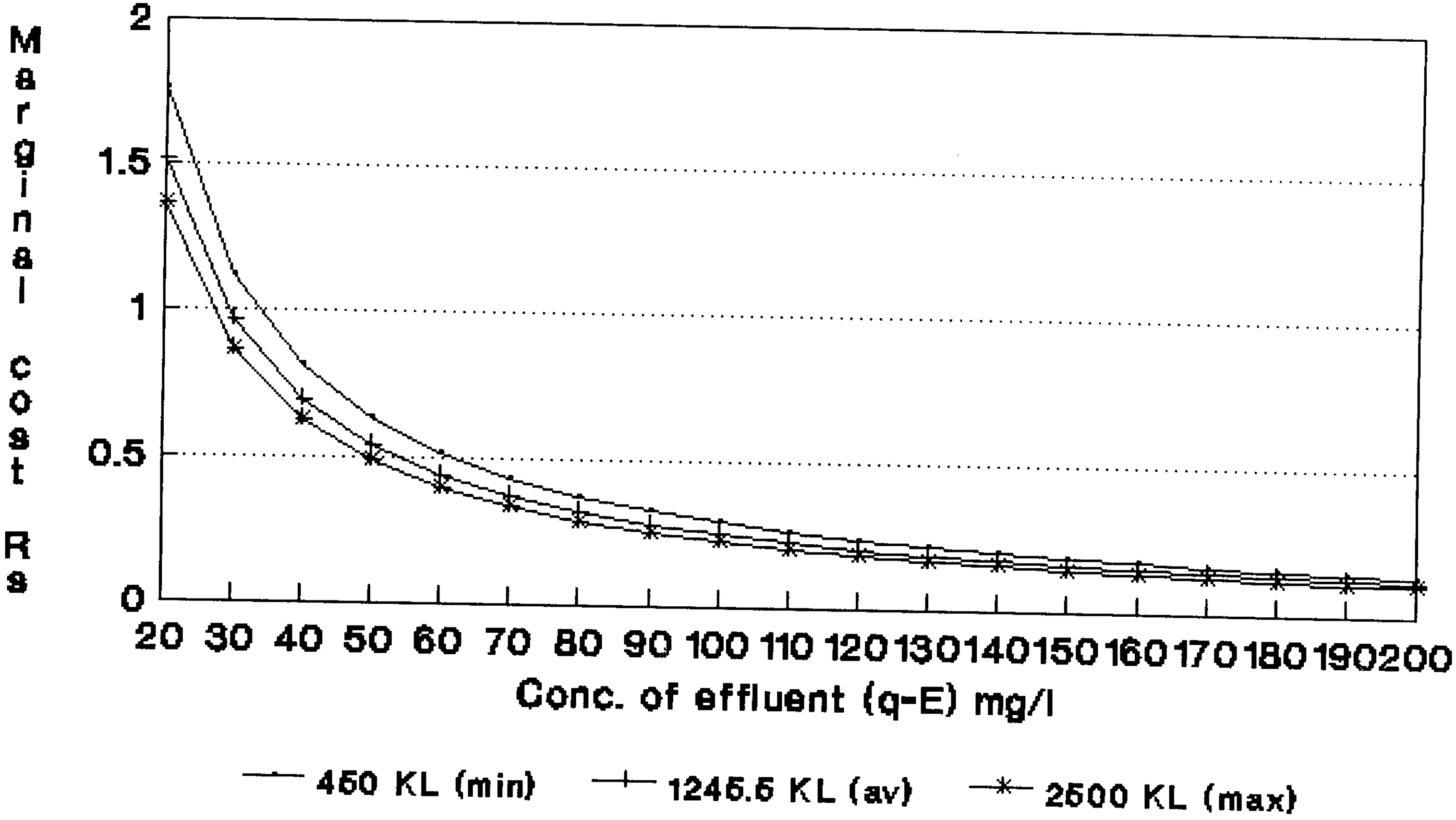
q-I = 926.51 mg/l (Average)



MARGINAL COST OF ABATEMENT

for different flow size (Q-I)

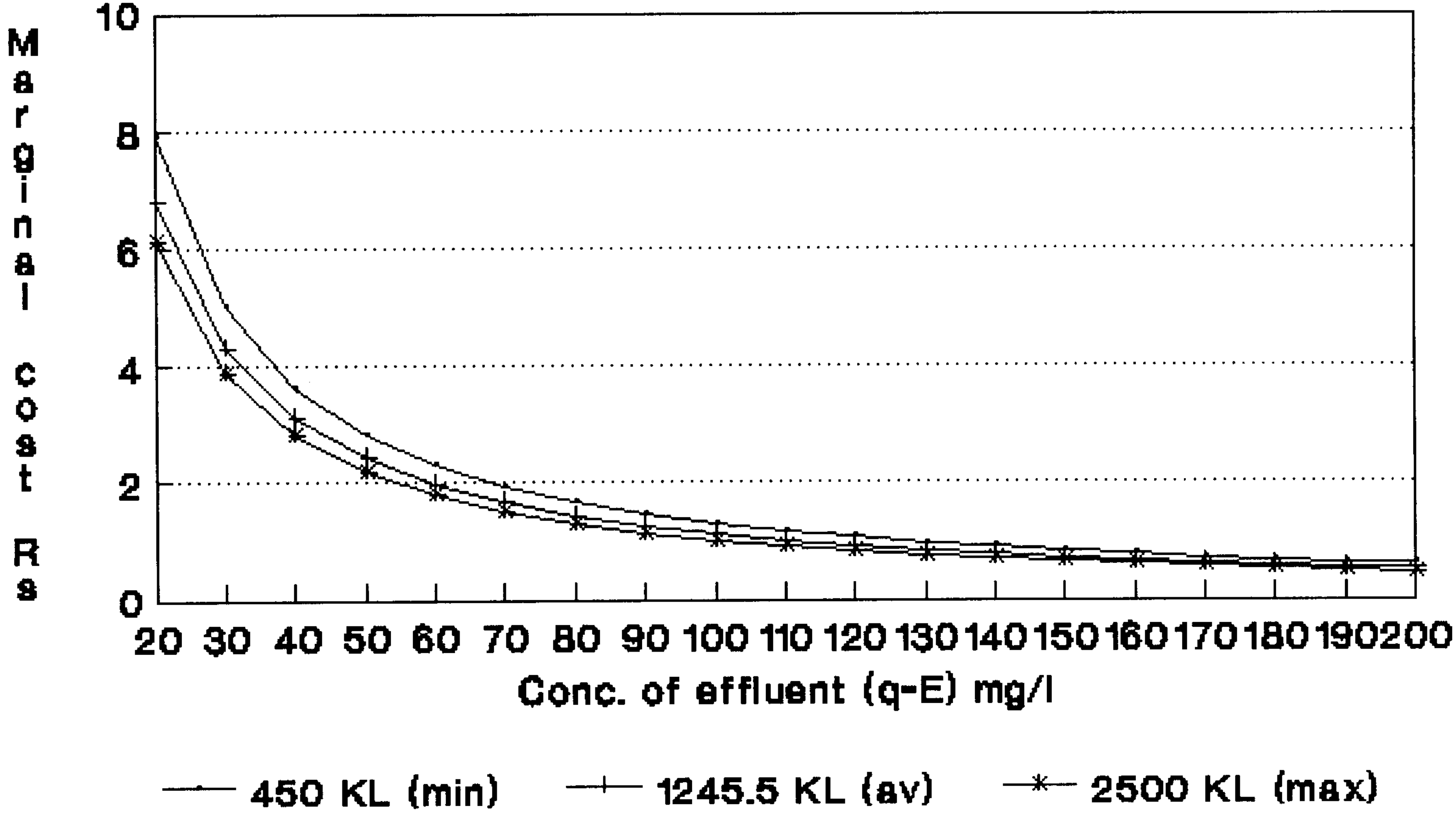
q-I = 197 mg/l (Minimum)



MARGINAL COST OF ABATEMENT

for different flow size (Q-I)

q-I = 1558 mg/l (Maximum)



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