Fiscal Instruments for Pollution Abatement: A Study of Distilleries in India

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1. Introduction

Environmental pollution is a by-product of economic activity. It can be viewed as a negative externality, which arises due to the absence of pricing or inadequate pricing of the environment. Lack of adequate pricing of the environment causes over-use of environmental resources. Thus, pollution through waste disposal exceeds the assimilative capacity of the environment, and imposes costs on the people. Existence of such costs has often led the policy makers to think entirely in terms of command and control (CAC) measures. While CAC measures can alter individual behaviour to make them undertake pollution abatement, these have not proved very effective in controlling environmental pollution due to certain inherent defects in them.[1] It is thus imperative to study how externalities may be reduced or eliminated through restructuring of poorly functioning market mechanism.

In principle, the optimum level of a pollution causing activity is that at which the social benefit from the activity and the social cost of the associated pollution get equalised at the margin. Alternatively, one may say that the use of the environment is optimal if the marginal pollution reduction costs are equal to the marginal damage costs. However, in practice, the above theoretical rule is difficult to apply due to difficulties in quantifying most forms of pollution damage. In the absence of such information, the clean-up cost required may serve as an alternative means to assess the likely adverse impacts of pollution on the environment and individuals.

Alternative approaches have been suggested for internalisation of externalities. Taxes and standards approach is one among them. The approach involves a pre-specified emission/ discharge standard for various pollutants, together a tax for each pollutant that is levied on the polluters if they exceed the prescribed norms. If these taxes are properly set, they will lead to an optimal use of environmental resources.

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[1] See Baumol and Oates (1971), and Panayotou (1991).

2. Objectives and Scope

This paper analyses in the Indian context the scope of using pollution taxes for inducing the distilleries to undertake adequate pollution abatement and bring down the level of pollutant [Biological Oxygen Demand (BOD)][2] to the levels prescribed by the legislation. The analysis is undertaken with the help of a non-linear programming model which makes it possible to study a choice available to the distilleries that they may use clean water for dilution of effluent stream after treating it up to a stage so as to reduce the BOD concentration level but avoid complete treatment of waste water. The paper examines how appropriate pricing of water together with pollution tax can be effective in reducing water pollution by distilleries. The distillery industry is chosen for the study because it is one of the most water polluting industries in India.

The model used for the analysis assumes that the distillery can extract a large quantity of ground water for dilution. It should be pointed out that extraction of ground water involves serious environmental costs in terms of lowering of water tables, and dilution can be justified if the economic cost of ground water extraction for the purpose of dilution of effluent stream compares favourably with the cost of treatment of polluted water in effluent treatment plants.

At the heart of the programming model is a pollution abatement cost function which relates the cost of abatement to the volume of waste water treated, the influent and effluent pollution concentration levels and input prices. The cost function has been estimated from cross-section data for a recent year. From the estimated cost function, marginal cost of abatement has been worked out which is useful for designing of pollution taxes.

In the next section, the estimates of cost function and marginal cost of abatement are presented and discussed. This is followed in Sections 4 and 5 by discussion on the programming model and its results. Section 6 presents a summary and the main conclusions.

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[2] The BOD is the measurement of the amount of oxygen required to oxidise various compounds present in water.

3. Pollution Abatement Cost Function

3.1 Specification of the Cost Function

From an engineering perspective, abatement means installing and operating processes which reduces 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 process 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.

The effluent treatment plant (ETP) can be considered as a production activity which has a production function as does any other production activity. Following Rossi, Young and Epp (1979), the production function for ETP may be defined as:

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

where O is the vector of quantity (Q_E) and quality (q_E) characteristics of effluent, I is the vector of quantity (Q_I) and quality (q_I) characteristics of influent, and W is the vector of various inputs used in abatement activity, such as labour, capital, energy and materials.[3]

For a cost minimising firm, a cost function relating the effluent treatment cost to the level of treatment can be derived by minimising abatement cost subject to the production function. The cost function derived may be represented as:

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

[3] 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 effluent is less damaging to the environment, the output of the ETP is not the effluent coming out of the ETP but the service provided by it in terms of reduced pollution level of waste water treated. It seems therefore better to specify the production function in implicit form as: ϕ (O, I, W) = 0.

where C denotes total cost of abatement and P is the vector of input prices.

Let us now consider a more specific case of only one pollutant. Let q_I and q_E be the pollution concentration levels in the influent and effluent streams. Then, taking

$$O = Q_E . q_E \quad \ldots (3)$$

$$I = Q_I . q_I \quad \ldots (4)$$

the cost function may be written as:

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

and using a Cobb-Douglas specification, the cost function can be written as:

$$C = A (Q_E . q_E)^b (Q_I . q_I)^c P_L^{\alpha} P_K^{\beta} P_E^{\gamma} P_M^{\delta} \quad \ldots (6)$$

In this equation, C is the total cost of treatment, $Q_E . q_E$ and $Q_I . q_I$ are the pollution load in influent and effluent streams, respectively, and P_L ,P_K , P_E and P_M are the prices of labour, capital, energy and materials input. The estimates of parameter α, β, γ and δ should be positive and add up to one (since the cost function should be linear homogeneous in input prices). The sign of b should be negative and that of c positive since an increase in the extent of pollution abatement done should lead to increase in the cost of abatement.

A limitation of the above specification is that the scale effect of the volume of waste water on cost is muddled between influent and effluent pollution loads. In order to capture the scale economies in treating a larger volume of waste water, the quantity of influent (Q_I) is included in equation (6) as an additional explanatory variable to yield the following equation:

$$C = A (Q_E . q_E)^b (Q_I . q_I)^c P_L^{\alpha} P_K^{\beta} P_E^{\gamma} P_M^{\delta} Q_I^{\theta} \quad \ldots (7)$$

Collecting and rearranging terms, the cost function may be written as:

$$C = A\, Q_I^{\eta} q_E^{\,b}\, q_I^{\,c}\, P_L^{\alpha} P_K^{\beta} P_E^{\gamma} P_M^{\delta} R^c \quad \ldots (8)$$

where $\eta = b + c + \theta$ and $R = Q_E / Q_I$.

The above equation gives the specification that has been used for estimating cost function for distilleries. However, the variable R had to be excluded, as information could not be obtained on the effluent volume (Q_E). The same specification has been used in the studies of Pandey (1997) and Ray and Ganguli (1997). Mehta, Mundle and Sankar (1994) have used the same specification, except that they have not included the price variables in the cost function.[4] James and Murty (1996) have used a similar specification. They have taken the ratio of q_I to q_E as one variable in the cost function. This involves a restrictive assumption that the parameters b and c are equal in numerical value.

Cross section data for 44 distilleries for a recent year (1996/97) has been used for estimating the cost function for this study. Data have been collected on various items of cost of the ETP of the firms and on various technical aspects of the operations of the ETP, such as the volume of waster water treated per day, the level of pollutants in the influent and effluent streams, etc.

Pollution abatement in distilleries primarily consists of treating waste water in order to bring the BOD, the COD, alkaline content and suspended solids within tolerance limits. The main treatment system consists of two stages viz. primary and secondary stages. The temperature, suspended solids and alkaline content are controlled in the pre-primary stage. The primary treatment normally removes 85 to 90 per cent of BOD in the influent water. In the secondary stage further treatment of the residual emitted after the primary treatment is done by aerobic system. Since BOD removal efficiency is an important parameter in designing the treatment plants for distillery effluents[5], BOD is taken as the single parameter measure of pollution in this paper. This implies that the data on abatement cost used here relates to controlling the level of various pollutants in a joint process, for which standards are specified and enforced by the regulating agencies.

[4] In this regard, the specification used by Mehta, Mundle and Sankar is similar to that used by Fraas and Munley (1984). In the Frass-Munley study, separate equations were estimated for capital cost and O&M cost.

[5] R. Vaidyanathan et. al, 1995.

3.2 Estimated Total Cost Function

The estimated total abatement cost function is shown below (t-ratios in parentheses):

$$\ln(C) = -13.489 + 0.955 \ln(Q_I) + 1.217 \ln(q_I) - 0.04515 \ln(q_E)$$
(44.05) (15.12) (-7.32)

$$+1.004 \ln(P_K) + 0.860 \ln(P_E)$$
(15.91) (13.03)

n = 44 Adjusted R-square = 0.96

It is seen that the estimated equation fits the data well. The coefficients of all the five explanatory variables are statistically significant.[6] The coefficients have the correct sign and are of plausible magnitude. The coefficients of q_I and q_E are quite different in the estimated equation which indicates that it would not have been right to use to ratio q_I to q_E as a variable in the cost function as has been done by James and Murty (1996).[7] Two other observations on the estimated total cost equation are: one, the estimates show significant economies of scale in the treatment of waste water, and two, initial reduction in BOD levels are achieved at relatively low cost, and as the BOD level is brought down, further reduction can be achieved only at an increasing cost.

3.3 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. Some recent studies in which marginal abatement cost has been estimated for Indian industries are by Mehta, Mundle and Sankar (1994) , James and Murty (1996) and Pandey (1997, 1998). The Mehta et al. (1994) study, making use of an engineering cost function, has estimated the

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[6] In the estimated equation, prices of capital and energy inputs have been used. Since there was no significant variation observed in the price of material this has not been considered in the estimated equation. The price of labour has also not been included in the estimated equation as the results were found to be poor.

[7] Dasgupta et al. (1996) have used effluent/influent ratio of pollutants in the abatement cost function, which has the same limitation as that of the James-Murty specification.

marginal cost of BOD reduction based on plant-level data of 22 paper and pulp 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. The study by Pandey (1997) estimates the marginal cost of BOD reduction from a behavioural cost function using plant level data for 53 sugar firms. The 1998 study by Pandey estimates marginal abatement cost for distilleries and paper and pulp firms.

Using the estimated total abatement cost function for distilleries (presented above), marginal cost of abatement has been worked out. The marginal cost of abatement is obtained as follows:

The estimated cost function may be written as

$$C = A\, Q_I^{\eta} q_E^{\,b}\, q_I^{\,c}\; P_K^{\beta}\, P_E^{\gamma}$$

Define R, pollution load removal as

$$R = Q_I\,(q_I - q_E)$$

Marginal cost of abatement is given by the partial derivative of C with respect to R.

$$\partial C / \partial R = [\partial C / \partial q_E]\,[\partial q_E / \partial R]$$

$$[\partial C / \partial q_E\,] = bA\, Q_I^{\eta} q_E^{\,b-1}\, q_I^{\,c}\; P_K^{\beta}\, P_E^{\gamma}$$

$$[\partial R / \partial q_E\,] = - Q_I\;; \quad [\partial q_E / \partial R] = -1/ Q_I$$

Therefore,

$$\partial C / \partial R = bA\, Q_I^{\eta} q_E^{\,b-1}\, q_I^{\,c}\; P_K^{\beta}\, P_E^{\gamma}\, \{-1/ Q_I\}$$

$$= - bA\, Q_I^{\eta-1} q_E^{\,b-1}\, q_I^{\,c}\; P_K^{\beta}\, P_E^{\gamma}$$

$$= -b\, C / \{ Q_I q_E \}$$

Marginal costs of pollution abatement at different BOD concentration levels of the effluent are presented in Table 1. Since marginal abatement costs for a given q_E will vary across influent pollution levels and volumes, we have taken the marginal cost of abatement at the values of Q_I and q_I of a representative firm (based on the averages for the distilleries covered in our sample).

Table 1 brings out clearly that at lower and lower BOD concentration levels of the effluent (q_E), the cost of further reduction in pollution load, i.e. the marginal cost of abatement, becomes higher and higher. The increase is particularly sharp after reaching the BOD concentration level of 100 mg/l.

4. The Programming Model

As mentioned earlier, for studying the responses of a representative distillery to fiscal and non-fiscal measures for environmental protection, we use a non-linear programming model. The basic structure of the model is explained in this section and the results are discussed in the following section.

Three scenarios are considered and separate programming exercises have been carried out for these scenarios. In the first scenario, we study the behaviour of the distillery when command-and-control instruments are used for the protection of environment. This modelling exercise reflects in a way the situation prevailing in India now, except for the fact that the regulation authorities are assumed to be able to enforce the pollution standards when it is known that in many cases the enforcement may be quite weak. As noted earlier, although pollution abatement involves treatment of waste water to bring the levels of BOD, COD, suspended solids and pH within specified tolerance limits, we consider only BOD for the analysis, since the jointness of the pollution abatement process makes it possible to take BOD as the single parameter of pollution. In trying to meet the BOD standards, the distillery has the option of treating waste water in treatment plants up to a stage and then use ground water for dilution so as to meet the standards set by the government.[8] To what extent dilution is done depends obviously on the cost of treatment and the cost of extracting ground water. Sensitivity exercise is carried out using different prices (cost) of ground water. This is useful for understanding the implications of economic pricing of ground water.

In the second scenario, command and control instruments are replaced by fiscal instruments. A load-based tax system is modelled. The pollution load is obtained from the BOD concentration in the final discharge and the volume of the discharge. The programming model is solved for various tax rates. Of particular interest is the rate of tax for which the distillery will bring down BOD concentration to the level which is presently specified as the standard.

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[8] Although legal requirements of waste water quality standards do not approve of "dilution" as a mode of treatment, a number of industries use dilution of waste water to bring the pollution concentrations to the desired levels so as to avoid legal action.

The third scenario is based on the recognition that load-based tax may be difficult to implement. It is felt that though BOD concentration level may be ascertained by periodic testing of waste water discharge from the distillery, the volume of discharge may be difficult to monitor. One possible scheme of pollution tax that may be imposed to take care of this problem is to obtain imputed pollution load based on (a) the BOD concentration level, (b) the volume of production and (c) engineering norms relating waste water generation to production volume. For this scheme of taxation, the programming exercise provides us the optimal solutions for the distillery in regard to the extent of dilution of waste water and the level of treatment of waste water at different rates of pollution tax and price of ground water.

The parameters, the equations and inequalities and the objective function constituting the programming model is given in the annexure.[9] The analysis is carried out for a distillery producing 15,000 KL of alcohol annually. It generates annually 375,000 KL of waste water (spent wash and process water). The basic choice before the distillery is how far it will treat waste water in the effluent treatment plants so as to bring down the BOD concentration level and to what extent it will resort to dilution of the effluent by making use of clean ground water extracted. Since extraction of ground water has an environmental cost in terms of depletion of the water table, there is obviously a social cost-benefit issue in terms of devoting resources for pollution abatement vis-à-vis extraction of ground water for dilution of effluents which may save some resources for meeting the pollution standards but involves an environmental cost.[10]

Given the choice available to the distillery and the various constraints, the distillery minimises the cost of complying with environment regulations. The cost of compliance

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[9] The parameters used in the model are based on the data collected in the survey and other technical information about distilleries obtained from other sources.

[10] The programming model used in the paper is based on a well-behaved cost function that involves a smooth marginal abatement cost curve. One cannot, however, rule out the possibilities of there being lumpy capital investments while upgrading effluent treatment plants to their tertiary level of treatment. The tertiary treatment systems which work towards reducing BOD levels to 30 mg/l could induce a kinked marginal abatement cost curve due to lumpiness of investment. This possible feature of the cost function could have been incorporated in the model by an appropriate construction of variables (as in mixed integer programming models). This has, however, not been attempted in the paper. It can be explored in future extensions of the analysis presented in the paper.

includes the cost of treatment, the cost of ground water, and the pollution tax burden on the distillery.

5. The Results

Table 2 shows the results of the programming exercise based on command-and-control scenario. It is assumed that by law the distillery is required to bring down the BOD concentration level of final discharge to 30 mg/l. The distillery realises that the specified pollution standard can be attained partly by undertaking treatment of waste water in the effluent treatment plant and partly by dilution with clean ground water. To what extent the distillery resorts to these two methods depends obviously on the cost of treatment and the price/cost of ground water. This is borne out by the table.

Based on a study by Gupta, Murty and Pandey (1989), the cost of ground water extraction has been estimated at Rs 0.25 per KL.[11] At this price of ground water, there is much incentive to dilute waste water after treatment so as to meet the specified pollution standards. The results presented in Table 2 show that the distillery brings down (by treatment) BOD level from 46000 mg/l to 116 mg/l and then uses 1075 thousand KL of ground water for dilution. The reason for this is obvious. The marginal of cost of abatement goes up at higher and higher levels of abatement. Thus, a stage comes when compared to the cost of treatment, the cost of dilution is found to be lower.

As the price of ground water is raised, the incentive for dilution goes down. Thus, if the price of ground water is Rupee 0.5 per KL, the distillery find it optimal to use only about 370 thousand KL of ground water for dilution. At ground water price of Rs 0.75 per KL, the optimal ground water quantity to be used for dilution is about 132 thousand KL. And, at still higher price of ground water of Rupee 1 per KL, the distillery finds it economic to use only 10 thousand KL of ground water for dilution.

The main point emerging from Table 2 is that if a firm is under compulsion to meet some specified pollution standard and if it has available to it ground water at a low price, then clean ground water will be used for dilution which in a sense runs counter to the objective of pollution control besides having environmental cost in terms of depletion of water table. It is

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[11] This reflects the financial cost of ground water extraction.

needless to say that economic pricing of ground water, reflecting the opportunity cost of water, will take care of this problem.[12] We return to this point later in our discussion.

Table 3 shows the results of the programming exercise based on a load-based pollution tax system. Under this scenario, there is no gain to the distillery in using ground water for dilution. Therefore, in none of the solutions of the programming exercise, ground water is extracted and used for dilution (even at price of Rs 0.25 per KL). What is of interest to note from the table is the extent of pollution abatement done at different tax rates. The results indicate that at a tax rate of Rs 0.5 per hundred grams of BOD, the BOD concentration level of final discharge is brought down to 189 mg/l. At higher tax rates the extent of treatment naturally goes up, and at a tax rate of Rs 3.5 per hundred grams of BOD, the distillery will bring down the BOD concentration level to 30 mg/l which is the present specified standard.

Table 4 pertains to the scenario in which imputed pollution load is used as the basis for taxation. As mentioned earlier, the imputed pollution load is obtained from the BOD concentration, the volume of production and the engineering norms of waste water generation of production of alcohol. Under this scheme of taxation, there is obviously an incentive to dilute waste water after treatment. The table shows for different tax rates and different prices of ground water, the BOD concentration levels of final discharge and the volume of ground water extracted for dilution. Two points emerge from the table. First, a high tax rate (on imputed pollution load) may force the distillery to bring down the BOD concentration of final discharge to a low level, but this will be achieved in part by dilution of waste water with clean ground water unless the price/cost of ground water is high. Second, for a given price of ground water, the incentive for dilution goes up at relatively higher tax rate. With a pollution tax rate of Rs 3.5 per 100 gram of BOD and the price of ground water at Rs 0.25 per KL (which is financial cost of ground water extraction), the distillery brings down BOD level of waste water to 107.5 mg/l by treatment and then uses 1080 thousand KL of ground water for dilution. If this tax rate is accompanied by a price of ground water of more than Rupee one, then the distillery has no incentive for dilution and will undertake treatment of waste water to the desired extent.

In the analysis above, we have considered the financial cost of ground water extraction in the absence of information on the economic cost of water. Our calculations for distilleries

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[12] In India, though there are regulations to check the clustering of bore wells, there is no pricing policy for ground water extraction.

show that if the price of water is set at Rs 1.25 per KL, then under the command and control regime as obtaining at present or if it is replaced by a regime based on pollution taxes, with a rate of tax of Rs 3.5 per 100 grams of BOD,[13] distilleries will undertake the necessary treatment of waste water and not indulge in dilution of effluent with clean ground water which involves an environmental cost. One may raise a question here on how the price of water suggested by us compares with the economic cost of water, and if in some regions the economic cost of water is much below the suggested price of Rs 1.25 per KL, will it right to raise the price of water to that level with a view to preventing dilution of waste water by clean water. To pursue this point further, one may also argue that if the cost of waste water treatment for a firm in a certain location is very high (at the margin), while the social cost of the damage that will occur if the firm resorts to dilution after undertaking treatment up to a stage is relatively less, there is a case for dilution. Accordingly, a water pricing policy that does not permit dilution under any circumstances can be questioned. In this context, we may note a weakness of the load based tax system. Howsoever high may the cost of treatment and howsoever low the economic price of ground water, the distilleries under this tax system have no incentive for dilution. In a sense, therefore, the imputed load based tax system which permits dilution, if the firm finds it economic to do so, can provide a better solution to the pollution problem besides being administratively more convenient. It is important, however, that the price of ground water be set at the right level (reflecting the economic cost of ground water) for the system to function properly.

The observation made above needs to be qualified. Dilution of waste water with clean water, though reduces the level of concentration of BOD in waste water, does not affect the quantum of pollution being discharged by a source. For this reason, as noted earlier, the current concentration based standards do not approve of "dilution" as a mode of pollution reduction. The practice of dilution of waste water, instead of its treatment, can have serious repercussions for the quality of water in certain water bodies or at certain discharge points in these water bodies where water quality is already poor. If one thinks about this problem carefully one would realise that since the existing quality of water and the absorptive capacity of the

[13] The tax is to be levied on all units of BOD exceeding the prescribed standard of 30 mg/l for discharge of industrial waste water in surface water bodies.

environment vary from region to region, an uniform set of standards should not be imposed for the whole country requiring firms of different industries and in different locations to meet the same standards irrespective of the difference in the costs of abatement. Once different standards are set for different regions depending on the local conditions and the price of ground water is set at the right level, there would be no case for dilution.

6. Conclusion

This paper analysed the scope of using pollution taxes for inducing distilleries in India to undertake adequate pollution abatement and bring the level of pollutant (BOD) in water discharged to the levels prescribed by the legislation. A major focus of the study was on the issue of dilution of effluent stream by clean ground water to meet the environment regulations. The analysis was undertaken using a non-linear programming model. For the purpose of the analysis, abatement cost function was estimated using cross-section data on distilleries.

The programming exercises brought out that if command and control instruments are used then at the prevailing financial costs of ground water extraction (Rs 0.25 per KL) there is strong incentive for the distillery to dilute effluent stream by clean ground water. The incentive tends to get reduced as ground water price is raised, and at a price of Rs 1.25 per KL the distillery does not find it economic to dilute effluent stream by extracting and mixing clean ground water. It seems therefore that, for distilleries, the ground water price needs to be set at Rs 1.25 per KL or higher[14] to curb substantially the tendency of using of ground water for dilution rather than undertaking treatment of waste water.

The analysis using a load-based pollution tax system shows that in that system the distillery has no incentive to use clean ground water for dilution. Our calculations show that at

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[14] The right price of ground water would vary from region to region depending on a number of factors such as the physical environment (e.g. the hardrock aquifers zones of Andhra Pradesh, Tamil Nadu, Karnataka and Maharashtra as contrasted to the hydrological conditions of Uttar Pradesh), availability of ground water, cost of extraction, value of ground water in alternate use, depth of water table, and the implications of high rates of ground water extraction for sustainability of agriculture and ground water based drinking water supply systems.

a tax rate of Rs 3.5 per hundred grams of BOD, the distillery will bring down BOD concentration level to 30 mg/l which is the present specified standard.

There are, however, difficulties in implementing a load-based pollution tax system. Thus, in the paper, a tax system based on imputed load is considered. In this framework, both the tax rate and the price of ground water become important in influencing the decision of the distillery about the extent of waste water treatment it will undertake and the quantity of ground water it will extract for dilution. The results of this programming exercise bring out that pollution tax has to be coupled with appropriate pricing of ground water to ensure that the distillery undertakes pollution abatement to the desired extent.

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Table 1: Marginal Cost of Abatement at Different Levels of Pollution Concentration in the Discharge from ETP

Concentration level (mg/l)	Cost per KL of waste water (Rs)	Marginal cost of abatement (Rs / 100 g)
5000	18.30	0.02
4500	18.39	0.02
4000	18.48	0.02
3500	18.60	0.02
3000	18.73	0.03
2500	18.88	0.03
2000	19.07	0.04
1500	19.32	0.06
1000	19.68	0.09
500	20.30	0.18
100	21.83	0.99
50	22.53	2.03
30	23.05	3.47

Note : The cost estimates are for waste water volume of 264,000 KL per annum. The BOD level of influent is taken as 45795 mg/l (sample average).

Table 2: Results of Programming Exercise - Command & Control Scenario: Treatment and dilution at different prices of ground water

Price of ground water	BOD con. level		Ground water mixed post-treatment
	pre-trtmt	post-trtmt	
(Rs/KL)	(mg/l)	(mg/l)	(000 KL)
0.25	46000	116.0	1075
0.40	46000	74.0	550
0.50	46000	59.8	372
0.75	46000	40.5	132
1.00	46000	30.8	10
1.25	46000	30.0	0

Table 3: Results of Programming Exercise - Load based Tax Scenario: BOD concentration and Tax burden at different rates of pollution tax

Tax rate (Rs per 100 gram of BOD)	BOD concentration level post-treatment mg/l	Tax burden (Rs 000)
0.10	882	320
0.20	454	318
0.50	189	298
1.00	97	251
1.50	66	203
2.00	50	150
2.50	41	103
3.00	34	45
3.50	30	0

Note: In these results, the optimal quantity of ground water to be extracted for dilution is zero at all the rates of tax chosen.

Table 4: Results of Programming Exercise - Imputed Load based tax Scenario: BOD concentration of Effluent and Volume of ground water extracted at different rates of tax and ground water price

Price of ground water (Rs per KL)	Tax rate (Rs per 100 gram BOD) 0.5	1.0	2.0	3.0	3.5
0.25	179.0	92.1	47.4	32.1	27.7
	[640.8]	[339.3]	[179.6]	[123.8]	[107.5]
	(967)	(1006)	(1047)	(1071)	(1080)
0.50	184.2	94.8	48.8	33.1	28.5
	[339.3]	[179.6]	[95.1]	[65.6]	[56.9]
	(316)	(336)	(356)	(369)	(374)
1.00	189.1	97.4	50.2	34.0	29.3
	[189.1]	[97.7]	[50.4]	[34.7]	[30.1]
	(0)	(1)	(1)	(8)	(9)

Note : Figures in parentheses are ground water extracted for dilution (000 KL). Those in square brackets are BOD concentration level post-treatment (mg/l). Those without brackets are BOD level in final discharge (mg/l).

Annexure: Programming Model

1. Basic parameters of the model are:

PRTBOD	pre-treatment BOD concentration level = 46000 mg/l
QUT	annual output (alcohol production) of the distillery = 15,000 KL
PRA	price of alcohol = Rs.7000 per KL
TR	tax rate = various values assigned in different programming exercises
PRGW	cost/ price of ground water = various values assigned in different programming exercises.
R1	Waste water (spent wash) generation per KL of alcohol produced = 15 KL/KL
R2	Waste water (process water) generation per KL of alcohol produced = 10 KL/KL

2. Variables (non-negative)

VOLW	volume of water treated
GWP	volume of ground water extracted
PSTBOD	post-treatment BOD concentration level
FBOD	BOD concentration level in final water discharge
VOUT	value of output
CT	cost of treatment (based on the cost function)
CGW	cost of ground water extraction
TBRDN	pollution tax burden on the distillery

3. Equations and Inequalities[15]

(i) $VOLW = R1*QUT + R2*QUT$

(ii) $VOUT = QUT * PRA$

(iii) $FBOD = (PSTBOD*VOLW)/(VOLW+GWP)$

(iv) $PRTBOD \geq PSTBOD \geq 30$

(v) $\ln CT = const + 0.955 \ln VOLW + 1.217 \ln PRTBOD - 0.04515 \ln PSTBOD$

(vi) $CGW = PRGW * GWP$

(vii) $TBRDN = TR * [(FBOD - 30) * (VOLW + GWP)]$ .. (model 2)

or

$TBRDN = TR * [(FBOD - 30) * VOLW]$ .... (model 3)

TBRDN is taken as zero if FBOD is 30 mg/l or less. In the command-and-control scenario, the equation for tax burden is removed and a constraint is imposed that the BOD concentration *level in the final discharge must be equal to 30 mg/l.*

4. Objective Function

The objective function is:

$$Z = CT + CGW + TBRDN$$

which is minimised subject to the constraints given above. Evidently, the objective of the distillery is to minimise the cost of complying with environment regulation.

15 The constant of the cost function includes the price variables which have been taken at the sample mean.