

PRICING OF DRINKING WATER :
An Application of Coase Two-Part Tariff

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ABSTRACT

An efficient and equitable rate structure for drinking water based on a modified version of Coase two-part tariff is developed and estimated for an urban water supply scheme in Kerala State, India. The cost function for drinking water is estimated from timeseries data and the demand function from a sample of cross-section data on urban consumers of piped water. The study identifies the socio-economic factors affecting water consumption in urban households and constructs the adult-equivalent scale, for the first time, in the consumption of potable water.

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By

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1. Introduction

Schemes for provision of drinking water - a basic human need - to large populations involve huge initial capital investment on fixed capital such as processing plants and infrastructure for distribution and on ongoing operational expenditures on administration, maintenance and repairs. Fixed capital once invested on a public utility could be, in principle treated as "land", provided the funds raised for such investment is a grant from the government. Seldom are such investments by the public sector made from own resources; in most cases it is the financial sector which lends the required funds. For making loan repayments, the expenditure incurred in capital investment has therefore to be recouped. It is also necessary to recover operational cost on an ongoing basis for the sustainability of the system. This would imply that the cost - fixed and variable - of production of water has to be recovered. Therefore, governments should formulate policies aimed at the financial viability, with efficiency and equity considerations of this sector. Pricing of water becomes the most important among such policies.

There are several ways of pricing potable water. Let us examine three methods that are most commonly used in practice. In the first method, the rate structure is determined on the basis of 'rateable value' or other characteristics of property owned by the household¹. The second way is to charge all the consumers a flat rate. The third is to price the households according to marginal cost of the metered consumption. Of these, the first is equitable but not efficient since the consumer is charged on the basis of 'rateable value' of the property but not on the basis of the resource cost of actual consumption. Obviously, the second method is neither equitable nor efficient. Pricing the metered consumption is efficient though not equitable. Under the marginalist rule, water is consumed only if the value of the additional unit is equal

¹ see Rajah and Smith (1993) for a survey of these methods and their application in UK,

to its resource cost which regulates consumption. But hardly any work exists in the developing countries in pricing of this social sector along marginal principles². The present exercise is an attempt in this direction made on the basis of a case study of an urban water supply in Kerala state, India.

The outline of the paper is as follows. Section 2 estimates the cost function for water supply using time series data. Section 3 deals with the socio-economic factors that influence the consumption of water from a sample survey. The theory of pricing of drinking water and its application are discussed in section 4. The implications of the results are discussed in the concluding section.

In order to identify the appropriate pricing model, one needs the nature of the cost function. This is taken up in the next section.

2. Cost function

A firm utilises a variety of productive services per unit of time to produce a certain flow of output. The relationship between cost and output then depends essentially upon three factors : (1) the production function; (2) the conditions of supply of factors of production to the firm; and (3) the optimality conditions. Under cost minimising behaviour, the above relationship is given by

$$\text{Minimise } C = W \cdot X \quad (1)$$

subject to $f(X) \geq O$.

where $O = f(X)$ is the standard production function;

and X , a column vector of 'n' inputs and W , a row vector of corresponding input prices.

The optimality condition gives us the long run cost function.

$$C = C(W, O) \quad (2)$$

² Whittington, et. al., (1990) is the only exception which is concerned with cost recovery of rural water supply. See also World Bank (1975).

For simplicity, we assume that the cost function satisfies all standard assumptions³.

If some inputs in the production function are fixed, we have the short run cost function:

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$$C = C(W_{n-k}, O, X_k) \quad (3)$$

where X_k is a vector of 'k' fixed inputs and W_{n-k} , the prices of remaining variable inputs.

Since the processing plant and machinery and the distribution line are fixed for the water supply, we estimate the short run cost function.

2.1 Statistical cost estimation

The urban water system supplies water to household sector and non-household sector. Therefore the cost of household consumption is to be estimated from the total cost of production. An earlier study shows that about 16% of the water supply is used by the non-household sector⁴. The cost of production of water for household sector is estimated as 84% of the total cost. The cost of supply of drinking water falls into two parts : (i) production cost and (ii) distribution cost. The former includes cost of treatment and of pumping of untreated and treated water and laboratory charges. The latter comprises cost of maintenance of distribution network, metering system, small line extensions and revenue collection as well as other administrative expenses. More specifically, the total variable cost (TVC) is defined as⁵

$$TVC_t = W_t + E_t + C_t + M_t \quad (4)$$

³ See Chambers (1988, p.52) for the assumptions.

⁴ Tata Consulting Engineers (1992).

⁵ Clark and Stevis (1981) have broken the cost structure into five categories; (1) the cost of pumping raw water from the intake; (2) the cost of purification; (3) the cost of transmitting the treated water through trunk mains; (4) the distribution cost; and (5) metering and allied activities, and laboratory and other services for analysing the quality of water.

Where

W_t = wages and salaries of the employees;

E_t = cost of electricity for production including yard lighting;

C_t = cost of chemicals including transportation charges; and

M_t = cost for maintenance, repair, and upkeep of building and fixed capital.

Opportunity cost of water is assumed to be zero for the purpose of this analysis.

The design of rate structure requires information on the marginal cost of production which can be calculated in two different ways. In the first method, cost is estimated as a function of input prices and output. In the second, cost is adjusted for input price effect using an appropriate index and is regressed on output⁶. The second method is used for the estimation. The construction of the input price index for deflating the variable cost is discussed in Appendix A.

The deflated average variable cost is then regressed on the output for the period, 1974/75 - 1991/92. Various functional forms were tried for the estimation and the best fitted function, the exponential function, is given below⁷.

$$\text{Log AVC} = 3.039 + 0.00004 * O \quad (5)$$

(11.32) (5.27)

Adj. $R^2 = 0.61$; Durbin-Watson = 1.96; $N = 18$; F-ratio = 27.73.

The estimated cost function indicates that the average variable cost and marginal cost increased exponentially during the period. For pricing this utility, an understanding of the factors affecting demand for water is required. The next section discusses the methodology of estimating the demand function.

⁶. Johnston (1960) for the methodology.

⁷ Appendix A for the source of data and measurement of variables.

3. Demand function

The consumption of water, just like consumption of any other commodity, is influenced by its price and income of the household⁸. Information on income of the household is very difficult to obtain. Hence socio-economic factors such as education, characteristics of housing and the ownership of durable assets have been used as the main determinants of household consumption. In the characteristics of housing, the variables included are: floor area per person; taps per person; bath rooms per person; the existence of flush units and garden; and the frequency of house cleaning. The consumption function of water becomes:

$$C = C(EN, TP, GN, FU, FA, BR, HC, DA, P) \quad (6)$$

Where

C = per capita consumption,

EN = education,

TP = taps per person,

GN = garden,

FU = flushing units,

FA = floor area per person,

BR = bath rooms per person,

HC = frequency of house cleaning,

DA = durable assets, and

P = price of water.

The effect of socio-economic variables on per capita consumption is postulated as follows. Obviously the own-price effect is negative. Education has a positive influence on consumption since educated households are more conscious about cleanliness. Of the household characteristics, floor area per person, existence of flushing units and bath rooms per person are postulated to have positive effect on demand for water. The presence and the type of garden also increase the requirement of water. Frequency of house cleaning has also an effect on water demand and the effect is postulated to be negative. Finally, the ownership of durable assets increases the consumption of households. The effects of the socio-economic variables on water consumption are summarised below.

⁸ See World Bank (1993), Mu, et. al., (1990), Schneider and Whitlatch (1991) for factors affecting demand for drinking water.

$$\delta C / \delta EN : > 0$$

$$\delta C / \delta TP : > 0$$

$$\delta C / \delta GN : > 0$$

$$\delta C / \delta FU : > 0$$

$$\delta C / \delta FA : > 0$$

$$\delta C / \delta BR : > 0$$

$$\delta C / \delta HC : < 0$$

$$\delta C / \delta DA : > 0$$

$$\delta C / \delta P : < 0$$

3.1. Data

The data for the study is obtained from a sample survey of 495 urban consumers of Trivandrum, the capital city of Kerala state, India. Details of the sample survey and the measurement of the variables are given in Appendix B.

The effect of consumption depends on household size in addition to the above socio-economic variables. This effect can be eliminated if consumption is calculated on a per capita basis. In order to calculate the per capita consumption of water, an estimate of adult equivalent scale (AES) is needed. Systematic estimates of AES are not available for water although they exist for food items. The next section deals with the estimation of AES for water from sample survey data.

3.2. Estimation of adult equivalent scale

The adult equivalent scales for sex and age have been separately worked out from the data on monthly consumption of water. The average monthly consumption of households was classified by sex and age. Children were grouped under two categories : (1) below five years of age; and (2) between 5 and 15 years of age. Children below 5 years use water normally only under strict supervision and control by their mothers and other adult members of the households. They require only much smaller quantities of water than persons in the higher age groups. Children between 5 and 15 years of age enjoy more freedom than those under 5 years in using water. Further their consumption level is also higher. Children are likely to be set free from parental restrictions by the time they reach the age of 15. It is with these

assumptions that the model is estimated using Prais-Houthakker method⁹.

Incremental average consumption of different sizes of household is given in Table 1.

[Table 1 goes here]

The AES is constructed from Table 1 in the following way. The highest average consumption, that is, the consumption of an adult female is taken as unity. The consumption of other categories have been scaled to this unit. The AES for water consumption thus constructed is: adult female = 1; adult male = 0.47; Children below the age of five = 0.06; and children between the age of five and fifteen = 0.11. It is interesting to compare AES of water with AES of food articles¹⁰. AES for food based on nutritional requirements is: adult male = 1; adult female = 0.92 and child below the age of fifteen = 0.52. This estimate shows the inappropriateness of using AES of food for non-food items in the calculation of per capita consumption of non food items. The above scale, AES for water, is used for the adjustment of household composition effect on consumption of water. Having estimated the per capita consumption of water, let us examine the impact of socio-economic variables on per capita consumption.

3.3. Estimation of the consumption function

Per capita consumption is estimated using the following specification.

$$C = \alpha_0 + \alpha_1 EN + \alpha_2 TP + \alpha_3 GN + \alpha_4 FU + \alpha_5 FA + \alpha_6 BR + \alpha_7 HC + \alpha_8 DA + u \quad (7)$$

Since the estimation is based on cross-section data, the price variable has not been included in the specification

[Table 2 goes here]

The estimate of equation (7) is given in model 1, Table 2. In the equation, floor area per person and bath rooms per person are significant at 1 % level; education and taps per person significant only at 10 %; and the durable assets and garden are not significant. The

⁹ Prais (1953) and Prais and Houthakker (1971) for details.

¹⁰ AES of food articles, known as Amsterdam scale, is from Deaton and Muellbauer (1980, p.193).

correlation matrix of the independent variables shows the following: (1) floor area per person is correlated with all other regressors; (2) the correlation is very high between taps per person, bath rooms per persons and floor area per person¹¹. This finding indicates that multicollinearity is a serious problem in the estimation. In order to overcome this, the ratio of bath rooms per person to taps per person (BTR) have been used and estimated the equation again. This is model II in Table 2. An interesting point to note is that the new variable is not significant and the t-value of floor area per person is very high. The high t-ratio and the significant correlation coefficients with all other regressors seem to suggest that the variable FA, may be a dominant variable. A separate regression with floor area per person alone confirms that it is indeed the case (see model III in Table 2). Therefore, the effect of the socio-economic variables is obtained by reestimating the equation without the dominant variable (model IV in Table 2). All the variables are significant either at 1 % or at 10 % level. The beta-coefficients of the socio-economic variables in model IV in Table 2 show that education, flushing units, durable goods and the type of garden influence consumption in ascending order of importance. All these variables are clearly proxies for the income of the households.

Having estimated the cost and the demand functions for drinking water, the question of the rate structure is taken up in the next section.

4. Rate structure

The theoretical basis of the present study is public utility pricing. It is well known that marginal cost pricing maximises social welfare and that it gives the efficient set of prices. If it is a natural monopoly then the marginal principle might end up as a loss making proposition since average cost is less than marginal cost. The earliest solutions for such a problem are: (1) Ramsey pricing; (2) Hotelling-Lerner solution; and (3) Coase two-part tariff¹². The Ramsey prices are defined for a natural monopoly producing 'm' products as follows.

¹¹Estimated correlation coefficient is significant at 1% level: $r(TP, BR) = 0.88$; $r(TP, FA) = 0.81$; $r(BR, FA) = 0.86$.

¹². See Ramsey (1927) and Coase (1946). There are two other methods suggested in the literature; Fully distributed cost method and Game-theoretic methods. The former lacks a theoretical basis and the latter needs some empirical support.

maximise CS (8)

(P_1, P_2, \dots, P_m)

subject to $PS = F$

where CS = consumer surplus;

PS = producer surplus;

F = fixed cost of the firm; and

p_1, P_2, \dots, P_m = prices of the 'm' products.

The prices which maximise (8) are called the Ramsey prices and the Lagrangian multiplier, λ , the Ramsey number. Under the assumption of constant cost and independent demand for the products, the first order conditions become ¹³

$$(P_i - C_i)/P_i = \lambda \epsilon_i \quad i = 1, 2, \dots, m \quad (9)$$

where C_i = marginal cost of i th product;

ϵ_i = own-price elasticity of demand for i th product; and

λ = Lagrangian multiplier.

Even though this model is not applicable to our study it has a very powerful implication for the rate structure of water. If we treat 'm' products as 'm' markets for water, Ramsey solution suggests that mark up should be higher for higher income groups since the demand for water is inelastic for higher income groups¹⁴. But the numerical solution of this problem is quite complicated since it requires the Ramsey number and the elasticities of demand. Brown and Sibley show that the price can be computed only under very restrictive conditions on the nature of the demand functions¹⁵. Hence we use here the Coase two-part tariff which is an improvement over the Hotelling-Lerner solution.

Hotelling-Lerner have suggested a method of pricing public utility. The suggestion is that the price should be charged according to the marginal cost and the loss, if any, should be

¹³ Baumol and Bradford (1970) for a formal proof.

¹⁴ There exists hardly any estimate on the price elasticity of water by income groups.

¹⁵ Brown and Sibley (1986, p. 41).

recovered from the public through taxation¹⁶. But Coase has demonstrated that "the Hotelling-Lerner solution would bring about a maldistribution of factors of production, a maldistribution of income and probably a loss similar to that, which the scheme was designed to avoid, but arises out of income taxes"¹⁷. To overcome this difficulty, Coase has proposed a two-part system of pricing.

Coase two-part tariff consists of two components for the price. The first component is the fixed entry fee which is equal to the total fixed cost divided by the total number of consumers. The second component is the user cost which is equal to the marginal cost of production. It is expected that all the consumers should pay the entry fee. Once the entry fee is paid it is left to the consumers to choose the quantity of consumption. But for a product which has absolutely no substitute and is a basic necessity, the welfare of the group of small quantity consumers is lower under two-part tariff than under uniform pricing, whereas large quantity consumer groups and the firm are better off in this situation as demonstrated in the diagram below¹⁸.

[Figure 1 goes here]

Consider two typical consumers of water; one from the smallest slab, say, S and the other from the biggest slab, say, B. Assume that the cross-price elasticity of demand for water is negligible. Let 'm' be the marginal cost of production which is constant. Consider the two pricing models; (1) uniform price; and (2) Coase two-part price. Let $Q_S(1)$ and $Q_B(1)$ be the consumption of the two groups under the uniform price P_1 , such that

$$P_1 = \text{Fixed cost}/(Q_S(1) + Q_B(1)) + m,$$

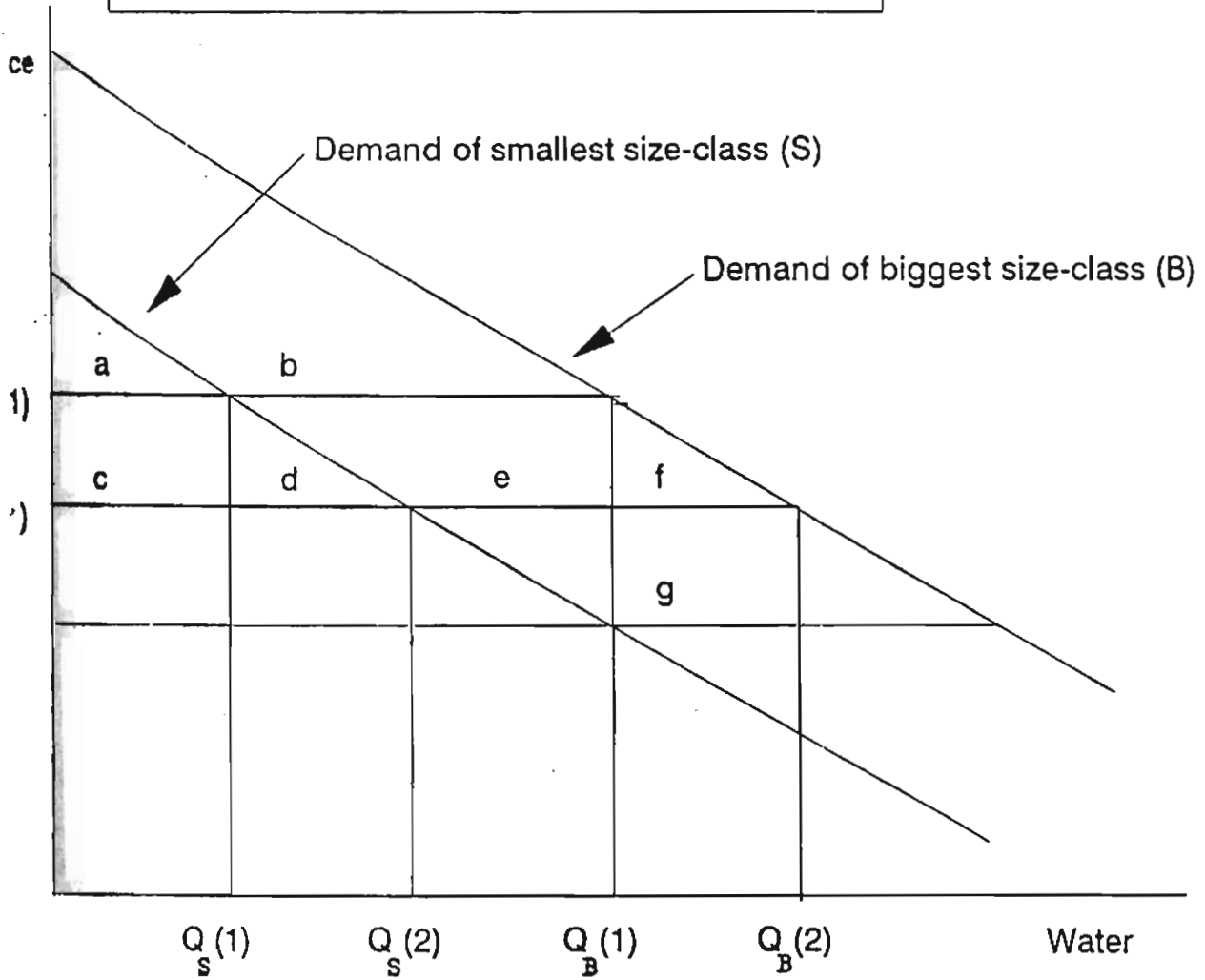
This formula simply means that at the average price, P_1 , the firm satisfies break-even condition.

¹⁶.Raj (1973) has proposed the same rule for water supply and sanitation.

¹⁷. Coase (1946, p. 180).

¹⁸. The figure is due to Brown and Sibley (1986, p. 69).

Fig.1: Welfare under linear versus nonlinear price



In the uniform pricing, consumer surplus is 'a' for S and 'a+b' for B. Now let P_2 be the marginal price (usage charge) with fixed entry fee, E,

$$E = (P_1 - P_2) Q_B(1) \quad (10)$$

Under nonuniform price S increases the consumer surplus by the trapezoidal region 'c+d'. But the entry fee is higher than the incremental consumer surplus. Therefore, S is better off under uniform pricing. But in the case of B, the increase in consumer surplus is 'c+d+e+f' and the consumer is left with a surplus 'f' after paying the entry fee. Therefore, B is better off under two-part tariff. It is also true that under two-part tariff, the firm also increases its surplus by 'g'. Consumer S, under welfare maximisation, would prefer to opt out, if possible, under two-part tariff. But in the case of water, it is very unlikely. One way to overcome the welfare loss is to fix the entry fee equal to the trapezoidal area 'c+d' so that surplus of S remains the same under both set of prices. Since this area is very difficult to estimate, we approximate it with the rectangular area, $(P_1 - P_2)Q_S(2)$. If this rectangular is fixed as entry fee for consumer S and the rest of fixed cost to B, then the nonlinear pricing is more equitable for lower income brackets. This modified formula simply suggests that if the entry fee is charged according to the proportion of output consumed, the welfare loss for the lower quantity consumers will be minimised under two-part tariff. Since the formula reduces the loss in consumer surplus for lower income groups, the modified version is followed for empirical analysis. As a result the multipart tariff reduces to Coase two-part tariff for each slab in application. However, the implementation of this pricing for a product assumes that it satisfies the following four conditions¹⁹: (1) the seller has monopoly power; (2) resale markets are limited or absent; (3) the seller can monitor customers' purchase; and (4) the seller has disaggregated demand data. These conditions are more or less satisfied in the case of drinking water. Now let us examine the above model empirically.

4.1. Estimation of entry fee

4.1.1. Theory

Fixed cost of water supply systems comprises cost of plant and machinery, water conveyance mains and distribution network. Administrative cost is also included in the calculation of fixed cost. If the life of fixed capital is known, then one could devise a formula for its recovery as discussed below.

¹⁹ Wilson (1993, p. 10).

Let I_0 be the initial investment with a life span of 't' periods. Suppose there are n_t piped water connections in year 't' and x_t the appropriate price index with base in the same year of investment. Then the entry fee can be calculated as follows.

There are two components to be recovered in any one period: (1) recovery of the initial capital outlay and (2) interest on the outlay. Let interest be charged only for the outstanding balance. If the principal is repaid uniformly over the life of the asset, the annual payment is equal to:

$$I = I_0/t$$

The interest for the first period is equal to

$$R_1 = I_0(1+r)^1$$

The total amount to be recovered from the households in a year is given by

$$\begin{aligned} I_1 &= I + R_1 \\ I_1 &= (I + I_0(1+r)^1) \\ &= \{I_0/t + I_0(1+r)^1\} \\ &= I_0\{1/t + (1+r)^1\} \end{aligned}$$

For the second year, the amount to be recovered is given by the formula

$$I_2 = I_0\{1/t + (1-1/t)(1+r)^{1-1}\}$$

...

For the kth year,

$$I_k = I_0[1/t + \{1 - (k-1)/t\} \{(1+r)^{t-k+1}\}]$$

The entry fee for kth year, E_k , is the given by,

$$E_k = I_k/n_k \tag{11}$$

where n_k is the total number of connections in year k.

The amount recovered in real and in nominal terms is the same only if there is no inflation. This is not a realistic assumption. If inflation exists, consumers gain and the government loses in real value of the initial outlay. In an inflationary world, this creates an inter-generational inequity in the recovery of annuity in real terms. This can be eliminated if inflation is also incorporated in the schedule of prices in the following way²⁰. Let the index of inflation (with the same base as the year of initial investment) be x_k in year k. Then the entry fee adjusted for inflation in year k is given by the formula:

$$E_k = I_k (1 + x_k)/n_k \tag{12}$$

The estimation of the entry fee is illustrated below.

²⁰ Jenkins and Harberger (1991, Chapter 6) suggest that inflation should be included in order to avoid incorrect project preparation and evaluation.

4.1.2. Estimation

Out of the two water treatment plants in the system under study, one has already crossed its life span. Therefore, only the investment on the second plant is considered for the calculation of entry fee. The first investment ²¹ in plant II was completed in 1977, followed by capacity addition in 1986. A dam for storage of water was also constructed in 1983. The life expectancy, according to engineering expectations, for both the plants and dam is fifty years. The entry fee for the year 1992 is calculated as follows. The annuity from the investment in three different years have been converted to 1992 prices²². The total annuity to be recovered in 1992 from the users are:

Annuity in 1992 from 1977 investment in plant = Rs. 2211672.77

Annuity in 1992 from 1986 investment in plant = Rs. 1285693.49

Annuity in 1992 from 1983 investment in dam = Rs. 2168700.09

Administrative cost in 1992 = Rs. 1303097.00

Total amount to be recovered = 2211672.77 + 1285693.49 + 2168700.09 + 1303097
= Rs. 6969163.00

Total number of connections during 1992 = 80782.

E = fixed entry fee per month = 6969163/(80782 * 12)
= Rs. 7.20.

The variable entry fee (VEF) can be estimated only if the proportion of consumption by size-class is available. This is obtained from the predicted demand using model III in Table 2. The resulting estimate is given in Table 3.

[Table 3 goes here]

The fixed entry fee per user is Rs. 7.20 but varies from Rs. 4.2 for the lowest class to Rs. 21.1 for the highest class in the variable case. This allocation in VEF implies that a cross-subsidy from the higher class to the lower class. For the design of rate structure, the user fee by size-

²¹. Though the treatment plant was commissioned in 1973, other works could be completed only during 1977, which is taken as the year of completion. I_0 includes the interest payments on the borrowed capital.

²² Appendix C for methodology.

class is needed which is the focus of the next section.

4.2. Estimation of user charge

The marginal cost function from equation (5) is given by,

$$MC = \exp^{(3.039 + 0.00004 O_i)} (1 + 0.00004 O_i) \quad (13)$$

The marginal cost is evaluated at annual output of each size - class on the basis of relative consumption method. Algebraically, the output of the i th class, O_i , is obtained from:

$$O_i = (C_i / \sum_{i=1}^N C_i) O \quad i = 1, \dots, N.$$

where O = annual production of water;

C_i = the predicted consumption of the households in the i th class from model III in Table 2; and N is the number of class intervals.

[Table 4 goes here]

The usage charge for each size class is equal to the marginal cost multiplied by the annual mean consumption per household. The usage charge in current prices for input prices is given in Col. 2 of Table 4. The tariff rate is the sum of the two components; entry fee plus usage charge. The rate structure under fixed and variable entry fee is given in Col. 5 and Col. 6 respectively. Under the fixed entry fee regime, a consumer has to pay Rs. 8.74 per month in the lowest class and Rs. 24.98 in the highest, whereby the rate of the highest class is three times that of the lowest. But in the case of VEF, the price to be paid by the consumer in the highest class is almost seven times that of in the lowest. Obviously, VEF has a cross subsidy from large consumers to the small. This subsidy, as shown earlier, is a transfer of a portion of the consumers' surplus gained due to nonlinear pricing.

5. Summary and conclusions

Pricing of drinking water falls in the general area of public utility pricing. Unless it is a natural monopoly, marginal prices generate the maximum social, consumer and producer, surplus. But this rule results in losses for a natural monopoly. In this situation, Ramsey has

suggested a second best rule for determining the prices which maximise consumers' surplus subject to the condition that the producers's surplus is equal to the fixed cost of production. But Ramsey prices are very difficult to calculate since it requires the estimates on Ramsey number and the elasticities of demand. Hotelling and Lerner have suggested an alternative model for determining an efficient set of prices based on cost function which is easier to implement empirically. Their solution is to charge the user the marginal cost and recover the loss through taxation. Coase has argued that this results in maldistribution of factors of production and income. Moreover, he argues that the taxation will generate loss among the tax payers defeating the purpose for which the price was designed. In order to overcome this defect in Hotelling-Lerner price, Coase has proposed an alternative pricing rule, a two-part tariff. This non-linear price simply adds an entry fee equal to the fixed cost of the utility per user to the marginal price of production. Such a rate structure is efficient but not equitable. An equitable version of the formula is developed and estimated for an urban piped water supply scheme in Trivandrum, the capital of the state of Kerala in India.

The modified Coase formula requires the estimates of cost of and demand for drinking water. The cost function estimated from timeseries data shows the cost is exponentially increasing. The socio-economic factors affecting demand for drinking water is estimated from a random sample of 495 urban households with piped water connections. Regression analysis shows that per capita floor area, educational level, the existence of garden and durable assets significantly influence water consumption. There exists no estimate in the literature on adult-equivalent scale (AES) in the consumption of water for the calculation of per capita consumption. The adult equivalent scale from the sample survey shows that the adult female uses almost double the quantity used by the adult male.

The entry fee for the year 1992 is obtained from the annuity that should be recovered from the users in the year 1992. The fixed entry fee is equal to the total annuity divided by the number of connections. VEF, on the other hand, is the ratio of the annuity to the corresponding number of connections in each size-class. Total annuity is fully distributed among the size-class using, the proportion of predicted consumption of the sample households whereas the total connections are distributed using the sample relative frequencies of the same. The entry fee, thus arrived at, is higher for higher size-class since their consumption is relatively more. The marginal cost - user charge - is estimated from the exponential function using average mean consumption of each size-class. The rate structure is the sum

of entry fee and user charge.

The case study clearly illustrates that it is possible to devise an efficient and equitable rate structure for water utility in practice using Coase two-part tariff.

The study indicates the need for further research in several areas concerned with this utility. Firstly, rate structure based on Ramsey's second best rule should be estimated using elasticity obtained from contingency valuation method. This rate structure should be compared with the prices from Coase two-part tariff. Secondly, a methodology for the measurement of productivity under second best rule should be developed for assessing the efficiency of production. One limitation of the model described supra is that it ignores the cost of transmission and distribution due to locational differences of the users. Strictly speaking, the marginal cost is lower for head-enders and more for tail-enders. This is an area worth pursuing in the future. Finally, the relevance of peak-load pricing should be examined, since the demand for potable water varies according to the time of the day as well as with seasons.

Appendix A

The period for cost estimation is from 1974-75 to 1991-92. The variables were measured in the following way.

I) Total variable costs (TVC)

Total variable costs are incurred essentially for the operation and maintenance of the system. The data were compiled from the primary records of Kerala Water Authority (KWA), the public agency responsible for water supply and sanitation in the state. Wages and salaries include remuneration paid to employees engaged in the operation and maintenance including supervisory staff up to the level of executive engineer and those engaged in revenue collection. Payments such as bonus, allowances for washing, uniform, overtime etc, and holiday wages are also included in this item. Information on all other items included in the variable cost has been taken from the primary records of KWA.

II) Output

The aggregate output of Trivandrum Water Supply System (TWSS) consists of two processing plants; Plant I and Plant II. The output data can be obtained either from venturi meters or from actual pumping hours of water pumps²³. Unfortunately, the complete primary records of the venturi meters and the log book of the pumping hours were not available. Therefore, we resort to the following method for the estimation of the output of the separate plants.

All the primary records on venturi meters and the log book of pumping hours of Plant I were irreparably lost due to the natural process of decay. The only input data available for the entire period was that of electricity consumption obtained from the records of electricity board. We have used the electricity-output ratio for the estimation of the output series. It is observed that treatment plant 1 was running at its optimum capacity output of 36 million litres

²³. Venturi meters are installed for the measurement of output. See Murugan (1993) for technical details.

per day (m.l.d.) in 1972/73 and has fallen to about 30 m.l.d. in 1991-92. But the electricity consumption during this period shows an upward trend. Therefore, the assumption of constant input-output ratio is not valid²⁴. The variable energy-output ratios for the period 1974/75 - 1991/92 were estimated from the growth rates of the actual energy-output ratios available for two years, 1972/73 and 1991/92. The inverse of the ratios thus obtained were multiplied by the actual electricity consumed in order to arrive at the output series.

The data on output of Plant II for the period 1983/84 - 1991/92 were compiled from the KWA registers of the daily hours of pumping and the discharge rates of the pumps. For the period, 1974/75 - 1982/83, the same methodology has been used for the estimation of output as in the case of plant I. Only difference is that the energy-output ratio remains constant since the plant is new.

iii) Input price index

A weighted average of consumer price index of industrial workers, price of electricity and price of chemicals has been used for the deflation of total variable cost. The weights are the proportions of each component in the total cost.

Appendix B

Sample survey was conducted from August to October 1992. Stratified random sampling was adopted to select the sample. One half of one per cent of the total number of constructions made within Trivandrum Corporation area as on 31 March 1992 was taken as the size of the sample. Sample households were drawn from all strata with probability proportionate to population using circular systematic method with a random start. Out of the 555 constructions in the sample only 495 were found suitable for the study²⁵. If a construction had no water connection in the sample, the adjacent unit in the same stratum

²⁴ Murugan (1993, p. 47) for details.

²⁵ See Murugan (1993).

with water connection was substituted. The variables were measured in the following way.

i) Education (EN)

Education refers to the highest education of any member of the household. The following values were assigned to :

EN = 1, for literate;

= 2, for primary education;

= 3, for secondary education;

= 4, for graduates/post graduates excluding professional qualifications;

= 5, for professional diploma holders;

= 6, professional degree holders; and

= 7, all other higher qualifications.

The values clearly assume higher water consumption for households with higher education.

(ii) Garden (GN)

The effect of garden on consumption of water is also measured in a similar way:

GN = 0, if the household has no garden;

= 1, if there is a garden; and

= 3, if there is a garden with lawn.

iii) Flushing units (FU)

The flushing unit in the household is measured as a binary variable:

FU = 1, if there exists a flushing unit;

= 0, otherwise.

(iv) Durable asset (DA)

The most difficult measurement is that of durable assets. Therefore, we have restricted our analysis only to those items with unambiguous effect on the use of water. More specifically, only cars, two - wheelers and three - wheelers are used for the present study and they are defined as follows:

- DA = 7, if the household has car, three- and two-wheelers;
- = 6, for car and three-wheelers;
- = 5, for car and two-wheelers;
- = 4, for three- and two- wheelers;
- = 3, for car only;
- = 2, for three-wheelers only; and
- = 1, for two-wheelers only.

Appendix C

For the estimation of inflation adjusted entry fee, three separate weighted indices of prices were constructed because of the differences in the constituent components of the fixed capital. For the construction of the index, wholesale prices of the following materials were considered: basic metals; alloys and metal products; and machinery and machine tools. The share of each component in the total fixed cost was taken as the weight of the price index.

Appendix D

The total connections in each size-class is obtained from multiplying the total connections by the proportions of connections in the sample. The variable entry fee for the first three size-classes is constant because we have combined them into one for the following reason. The first size-class has very few consumers compared to the second and the third. As a result the variable entry fee formula gives a higher rate for the first than for the second and the third. In order to avoid this problem we have treated them as a single class.

[Table D1 goes here]

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Table 1: Household average monthly consumption by sex and age

| Sl.no. | Household size | Average consumption kilolitre/month |
|--------|--|--|
| (1) | (2) | (3) |
| 1 | 1 Male and 1 female | 15.79 |
| 2 | 1 Male, 1 female and 1 child < 5 years. | 16.13 |
| 3 | 1 Male, 1 female, 1 child < 5 years and 1 child 5 to 15 | 16.79 |
| 4 | 2 Male and 1 female | 18.53 |
| 5 | 1 Male and 2 female | 21.58 |
| 6 | Adult male (4 - 1) | 2.74 |
| 7 | Adult female (5 - 1) | 5.79 |
| 8 | Child < 5 years (2 - 1) | 0.34 |
| 9 | Child 5 to 15 years (3 - 2) | 0.66 |

Source: Sample Survey.

Table 2: Regression estimates of consumption of water

| Variables | Model I | Model II | Model III | Model IV |
|----------------------------------|--------------------|--------------------|------------------|----------------------|
| (1) | (2) | (3) | (4) | (5) |
| Constant | 3.050 (4.73)* | 3.349 (4.18)* | 4.113 (18.2)* | 4.604 (4.65)* |
| Education (EN) | 0.315 (1.77)** | 0.306 (1.66)** | - | 0.916 (4.06)* |
| Garden (GN) | 0.374 (1.31) | 0.382 (1.30) | - | 0.591 (1.62)** |
| Flushing units (FU) | - 0.232 (-0.54) | 0.412 (0.96) | - | 1.687 (3.24)* |
| Floor area per person (FA) | 0.0032 (4.32)* | 0.007 (16.3)* | 0.007 (19.4)* | - |
| Frequency of house cleaning (HC) | - 0.002 (-0.02) | 0.002 (0.02) | - | - 0.201 (-1.87)** |
| Durable assets (DA) | 0.125 (0.93) | 0.157 (1.13) | - | 0.296 (1.72)** |
| Bath room-tap ratio (BTR) | - | - 0.604 (-1.11) | - | -1.090 (-1.62)** |
| Taps per person (TP) | 0.362 (1.8)** | - | - | - |
| Bath rooms per person (BR) | 1.592 (3.1)* | - | - | - |
| Adj.R. ² | 0.48 | 0.44 | 0.43 | 0.14 |
| F-ratio | 57.1 | 57.5 | 377.1 | 14.8 |
| Sample size | 495 | 495 | 495 | 495 |

* Significant at 1% level. ** Significant at 10% level. - Variable not included.
Source: Sample Survey.

Table 3: Estimation of variable entry fee

| Size-class (K.l.) | Number of Households | | Mean FA (Sq.ft.) | Mean PCC/month (K.l.) | Annual fixed cost (Rs.) | Variable entry fee (Rs./month) |
|-------------------|----------------------|------------|------------------|-----------------------|-------------------------|--------------------------------|
| | sample | population | | | | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| <10 | 26 | 4343 | 401.20 | 7.09 | 76619.49 | 4.21 |
| 10.01-15 | 185 | 30191 | 389.37 | 7.01 | 75690.23 | 4.21 |
| 15.01-20 | 127 | 20726 | 444.67 | 7.42 | 80127.61 | 4.21 |
| 20.01-25 | 61 | 9955 | 479.70 | 7.68 | 82934.49 | 8.33 |
| 25.01-30 | 43 | 7017 | 480.36 | 7.68 | 82991.45 | 11.83 |
| 30.01-35 | 26 | 4243 | 562.68 | 8.29 | 89596.96 | 21.10 |
| >35 | 27 | 4406 | 602.34 | 8.59 | 92779.36 | 21.10 |
| Total | 495 | 80782 | - | 53.75 | 6969163.00 | - |

Source:- (1). Sample Survey.

(2). Government of Kerala (various issues).

- Notes:-
- (1) Col.(3) is obtained from multiplying the total number of connections in 1992 by the sample relative frequencies.
 - (2) Col.(5) is based on the dominant variable model III in Table 2.
 - (3) Col. (6) is the annuity in 1992 allocated on the basis of the relative consumption of the sample households.
 - (4) Col. (7) = Col. (6)/Col. (3).
 - (5) K.l. = Kilolitre; FA = Floor area per person; and PCC = predicted per capita consumption.

Table 4: Rate structure for drinking water for the year 1992 (rupees/month)

| Size-class (K.l.) | User fee (current-price) | Entry fee | | Coase two-part tariff | |
|-------------------|--------------------------|-----------|----------|-----------------------|----------|
| | | fixed | variable | fixed | variable |
| (1) | (2) | (3) | (4) | (5) | (6) |
| < 10 | 1.54 | 7.20 | 4.21 | 8.74 | 5.75 |
| 10.01-15 | 2.56 | 7.20 | 4.21 | 9.76 | 6.77 |
| 15.01-20 | 3.75 | 7.20 | 4.21 | 10.95 | 7.96 |
| 20.01-25 | 6.88 | 7.20 | 8.33 | 14.08 | 15.21 |
| 25.01-30 | 8.88 | 7.20 | 11.83 | 15.86 | 20.49 |
| 30.01-35 | 12.34 | 7.20 | 21.10 | 19.54 | 33.44 |
| > 35 | 17.78 | 7.20 | 21.10 | 24.98 | 38.88 |

Source :- Table D1 in Appendix 1.

- Notes :-
- (1) Col.(5) = Col.(2) + Col. (3).
 - (2) Col.(6) = Col.(2) + Col. (4)

Table D1: Estimation of user fee

| Size-class (K.L.) | Annual output (M.l) | Cumulative | MC | Mean consumption rate (K.l./h.h) | Annual rate | Monthly rate (Rs./K.l.) | User fee (current prices) | Household size (AES) |
|-------------------|---------------------|------------|--------|----------------------------------|-------------|-------------------------|---------------------------|----------------------|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| <10 | 4854.17 | 4854.17 | 30.28 | 213.37 | 6.46 | 0.54 | 1.54 | 2.51 |
| 10.01-15 | 4794.04 | 9648.21 | 42.58 | 252.00 | 10.73 | 0.89 | 2.56 | 3.00 |
| 15.01-20 | 5075.09 | 14723.30 | 59.80 | 263.22 | 15.74 | 1.31 | 3.75 | 2.96 |
| 20.01-25 | 5253.13 | 19976.43 | 83.54 | 345.49 | 28.86 | 2.41 | 6.88 | 2.75 |
| 25.01-30 | 5256.48 | 25232.91 | 115.14 | 315.39 | 36.31 | 3.02 | 8.66 | 3.42 |
| 30.01-35 | 5674.86 | 30907.77 | 160.80 | 321.89 | 51.76 | 4.31 | 12.34 | 3.24 |
| >35 | 5876.43 | 36784.20 | 224.78 | 331.67 | 74.55 | 6.21 | 17.78 | 3.22 |

Source:- 1. Sample Survey.
2. Government of Kerala (various issues).

- Notes:- (1) Col.2. is obtained by applying the sample proportion of consumption to the annual production in million litres (M.l) during 1992.
- (2) Col.4. is the marginal cost, MC, in constant prices corresponding to the output in col.3 from equation (13) in the text.
- (3) Col.5. is the annual mean consumption per household in the sample calculated using the formula;
monthly per capita consumption of each size-class * Col.9 * 12.
- (4) Col.6. = Col.5 * Col.4 / 1000.
- (5) Col.7. = Col.6 / 12.
- (6) Col.8. = Col.7 * 2.862, where 2.862 is the increase in input prices from the base year 1971 = 100.

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