THE WORLD BANK

Internal Discussion Paper

LATIN AMERICA AND THE CARIBBEAN REGION SERIES

Report No. IDP-19

Principles of Water Supply Pricing in Developing Countries

Mohan Munasinghe

June 1988

Infrastructure Operations

Country Department I

LAC DISCUSSION PAPER SERIES

Report No.	Title, Author and Date
IDP-3	"An Analysis of the Sources of Earnings Variation Among Brazilian Males" by Marcelo Dabos and George Psacharopoulos, December 1987
IDP-4	"The Efficiency and Effectiveness of Export Credit and Export Credit Insurance Programs" by Bruce Fitzgerald and Terry Monson (Consultant), December 1987
IDP-9	"Export Processing Zones: The Economics of Offshore Manufacturing" by Peter G. Warr (Consultant), August 1987
IDP-10	"Dumping, Anti-dumping and Efficiency" by Bruce Yandle and Elizabeth M. Young (Consultants), August 1987
IDP-11	"The Regulation of the Quality of Traded Commodities and Services" by Simon Rottenberg and Bruce Yandle (Consultants), June 1987
IDP-12	"Argentina: Problems for Achieving Macro Stability" by F. Desmond McCarthy and Alfredo E. Thorne, January 1988
IDP-13	"Argentina: Towards the Year 2000" by F. Desmond McCarthy, June 1987
IDP-14	"Trade Liberalization: The Lessons of Experience", Papers presented in the conference "Toward a New Trade Policy for Brazil", Sao Paulo, April 11 and 12, 1988
IDP-16	"Aspects of Privatization: The Case of Argentina 1976-81" by R. Luders (consultant), April 1988
IDP-17	"Aspects of Privatization: The Case of Chile 1974-85", by D. Hachette (consultant), April 1988
IDP-18	"Privatization in Argentina and Chile: Lessons from a Comparison" D. Hachette and R. Luders (consultants), April 1988

Table of Contents

Page

ABSTRACT

This paper establishes a framework for water supply pricing, reviews the basic theory of marginal cost pricing applicable to the water sector, and summarizes recent tariff structures. The adaptation of the theory for practical application in relation to the objectives of water supply pricing policy results in a two-stage procedure for tariff setting. First, the detailed structure of the strict long-run marginal costs (LRMC) of supply which meet the economic efficiency criterion are computed. Second, the strict LRMC is adjusted to arrive at an appropriate realistic tariff schedule which satisfies other constraints, including economic second best and social lifeline rate considerations, financial needs, simplicity of metering and billing, etc.

PRINCIPLES OF WATER SUPPLY PRICING IN DEVELOPING COUNTRIES

Mohan Munasinghe1/

I. INTRODUCTION AND OVERVIEW

Adequate potable water supply and sewerage services are now considered an essential requirement of modern societies. Traditionally, water supply pricing policy in most countries has been determined mainly on the basis of financial or accounting criteria, e.g., raising sufficient sales revenues to meet operating expenses and debt service requirements while providing a reasonable contribution towards the capital required for future system expansion.

However, in recent times several new factors have arisen, including the rapid growth of demand, increases in supply costs, dwindling availability of cheap water resources, and the expansion of water supply services into regions of lower consumer density (especially rural areas) at relatively high unit costs.

1/ The author is Chief, Infrastructure and Energy Operations Division, LAC Country Department I. This paper was presented at the Water Supply and Sewerage Tariff Conference, Brasilia, Brazil, April 26-28, 1988. The author is grateful to Robin Bates, Emilio Rodriquez, Carlos Velez and Alex McPhail for helpful comments.

These developments have led to increasing emphasis being laid on the use of economic principles in order to produce and consume water efficiently, while conserving scarce resources, and meeting various national objectives.

In particular, attention has been paid to the use of marginal cost pricing policies in the water sector. We note that price is an effective technique of demand management especially in the long run. The effects of pricing policy are also greatly enhanced by coordinating it properly with other demand management tools such as financial and tax incentives, as well as improvements in hardware that facilitate conservation efforts in the short run.

The objectives of water tariff policy in the national context, and a pricing framework based on long-run marginal costs (LRMC) which meets these requirements, are summarized in this section. In Section II, the economic principles underlying the LRMC approach are described, and in Section III contain a framework for calculating strict LRMC, and a summary of special issues arising from sewerage service costs. The process of adjusting LRMC to devise a practical tariff structure which meets other national constraints is discussed in Section IV. Section V contains a review of pricing structures currently used in several countries.

Requirements of a Water Tariff

The modern approach to water supply pricing recognizes the existence of several objectives or criteria, not all of which are mutually consistent. First, national economic resources must be allocated efficiently, not only among different sectors of the economy, but within the water sector. This implies that cost-reflecting prices must be used to indicate to the water consumers the true economic costs of supplying their specific needs, so that supply and demand can be matched efficiently.

Second, certain principles relating to fairness and equity must be satisfied, including: (a) the fair allocation of costs among consumers according to the burdens they impose on the system; (b) the assurance of a reasonable degree of price stability and the avoidance of large price fluctuations from year to year; and (c) the provision of a minimum level of service to persons who may not be able to afford the full cost.

Third, as described earlier, the water prices should raise sufficient revenues to meet the financial requirements of the supply utility. Fourth, the water tariff structure must be simple enough to comprehend and facilitate the metering and billing of customers. Fifth, and finally, other economic and political factors must also be considered. These might include, for example, subsidized water supply to specific sectors (in order to enhance growth) or to certain geographic areas (for regional development). Clearly, such subsidies would give rise to additional economic costs and inefficiency.

Since the above criteria are often in conflict with one another, it is necessary to accept certain tradeoffs between them. The LRMC approach to price setting described below has both the analytical rigor and inherent flexibility to provide a tariff structure that is responsive to these basic objectives.

LRMC-Based Tariffs

A tariff based on LRMC is consistent with the first objective, that is, the efficient allocation of scarce resources. While the traditional accounting approach is concerned with the recovery of historical or sunk costs, in the LRMC calculation the important consideration is the amount of future resources used or saved by consumer decisions. Since water prices are the amounts paid for increments of consumption, in general they should reflect the incremental cost incurred. Supply costs increase if existing consumers increase their demand or if new consumers are connected to the system. Therefore, prices that act as a signal to consumers should be related to the economic value of present and future resources required to meet consumption changes. The accounting approach that uses historical asset values and embedded costs implies that future economic resources will be as cheap or as expensive as they were in the past. This could lead to overinvestment and waste, or underinvestment and the additional costs of unnecessary scarcity.

To promote better utilization of capacity, the LRMC approach permits the structuring of prices so that they vary according to the marginal costs of serving demands: (a) by different consumer categories; (b) in different seasons; (c) by magnitude of consumption; (d) in different geographical areas; and so on.

In particular, with an appropriate choice of dry and wet periods, structuring the LRMC-based tariffs by time of use generally leads to the conclusion that in the dry season consumers should pay higher charges than in the wet season. Similarly, analysis of LRMC by volume of water used usually indicates that bulk consumers impose lower per unit costs on the system than smaller retail users.

The structuring of LRMC-based tariffs also meets subcategories (a) and (b) of the second, or fairness, objective mentioned earlier. The economic resource costs of future consumption are allocated as far as possible among the customers according to the incremental costs they impose on the water system. In the traditional approach, fairness was often defined rather narrowly and led to the arbitrary allocation of accounting costs to various consumers, thus violating the economic efficiency criterion. Because the LRMC method deals with future costs over a long period--usually at least 5 to 10 years--the resulting prices (in constant terms) tend to be quite stable over time. This smoothing out of costs over a long period is especially important given the capital indivisibilities or lumpiness of water system investments.

The LRMC method uses economic opportunity costs (or shadow prices-especially for capital, labor, and materials) instead of purely financial costs, and takes externalities into consideration wherever possible, thus further strengthening the link with efficient resource allocation. Externalities are especially important for sewerage services, as discussed later in Section III. The development of LRMC-based tariff structures, which also meet the other objectives of pricing policy mentioned earlier, are discussed next.

Practical Tariff Setting

The first stage of the LRMC approach is the calculation of pure or strict LRMC that reflect the economic efficiency criterion. If price was set strictly equal to LRMC, consumers could indicate their willingness to pay for more consumption, thus signaling the justification of further investment to expand capacity.

In the send stage of tariff setting, ways are sought in which the strict LRMC may be adjusted to meet the other objectives, among which the financial requirement is most important. If prices were set equal to strict LRMC, it is likely that there will be a financial surplus. This is because marginal costs tend to be higher than average costs when the unit costs of supply are increasing. In principle, financial surpluses of the utility may be taxed away by the state, but in practice the use of water pricing policy as a tool for raising government revenues is usually politically unpopular and rarely applied. However, such surplus revenues can also be utilized in a way that is consistent with the other objectives. For example, the connection charges can be subsidized without violating the LRMC price, or low-income consumers could be provided with a subsidized block of water to meet their basic requirement, thus satisfying sociopolitical objectives. Conversely, if marginal costs are below average costs--typically as a result of economies of scale--then pricing at the strict LRMC will lead to a financial deficit. This will have to be made up, for example, by higher lump sum connection charges, flat rate charges, or even government subsidies.

Another reason for deviating from the strict LRMC arises because of second-best considerations. When prices elsewhere in the economy do not reflect marginal costs, then departures from the strict marginal cost pricing rule for water supply services would be justified. In some cases, pricing water below the LRMC may be justified, to prevent excessive use of alternative supplies. For example, if incentives are provided to install wells or develop other water resources privately, then charging the full marginal cost for public water supplied to industrial consumers may encourage them to use their own supplies, even when this is economically less efficient from a national perspective. Since the computation of strict LRMC is based on the water utility's least cost expansion program, LRMC may also need to be modified by short-term considerations if previously unforeseen events make the long-run system plan suboptimal in the short run. Typical examples include a sudden reduction in demand growth and a large excess of installed capacity that may justify somewhat reduced charges, or a rapid unforeseen increase in supply costs, which could warrant a short-term water tariff surcharge.

As discussed earlier, the LRMC approach permits a high degree of tariff structuring. However, data constraints and the objective of simplifying metering and billing procedures usually requires that there should be practical limit to differentiation of tariffs by : (a) major customer categories--residential, industrial, commercial, special, rural, and so on; (b) consumption levels (bulk and retail); (c) time of use (wet or dry season); and (d) geographic region. Finally, various other constraints also may be incorporated into the LRMC based tariffs, such as the political requirement of having a uniform national tariff, subsidizing rural water supply, and so on. In each case, however, such deviations from LRMC will impose an efficiency cost on the economy.

Summary

In the first stage of calculating LRMC, the economic (first best) efficiency objectives of tariff setting are satisfied, because the method of calculation is based on future economic resource costs rather than sunk costs, and also incorporates economic considerations such as shadow prices and externalities. The structuring of marginal costs permits an efficient and fair allocation of the tariff burden on consumers. In the second stage of developing an LRMC-based tariff, deviations from strict LRMC are considered to meet important financial, social, economic (second best), and political criteria. This second step of adjusting strict LRMC is generally as important as the first stage calculation.

The LRMC approach provides an explicit framework for analyzing system costs and setting tariffs. If departures from the strict LRMC are required for noneconomic reasons, then the economic efficiency cost of these deviations may be estimated roughly, by comparing the impact of the modified tariff relative to (benchmark) strict LRMC. Since the cost structure may be studied in considerable detail during the LRMC calculations, this analysis also helps to pinpoint weaknesses and inefficiencies in the various parts of the water supply system--for example, overinvestment, unbalanced investment, or excessive losses at various points in the system, in different geographic areas, and so on. This aspect is particularly useful in improving system expansion planning.

Finally, any LRMC-based tariff is a compromise between many different objectives. Therefore, there is no ideal tariff. However, by using the LRMC approach, it is possible to revise and improve the tariff on a consistent and ongoing basis, and thereby approach the optimum price over a period of several years, without subjecting long-standing consumers to unfair shocks, in the form of large abrupt price changes.

II. ECONOMICS OF MARGINAL COST PRICING

Marginal cost pricing theory dates back to the pathbreaking efforts of Dupuit [6] and Hotelling [8], [12], [13]. The development of the theory, especially for application in the electric power sector, received a strong impetus from the 1950's [2], [3], [15], [19]. Recent work has led to developments in peak period pricing, incorporation of the effects of uncertainty and the costs of shortages, etc. [4], [9], [11], [16], [17], [18]. This section briefly reviews the basic principles of marginal cost pricing and some recent developments.

Basic Marginal Cost Theory

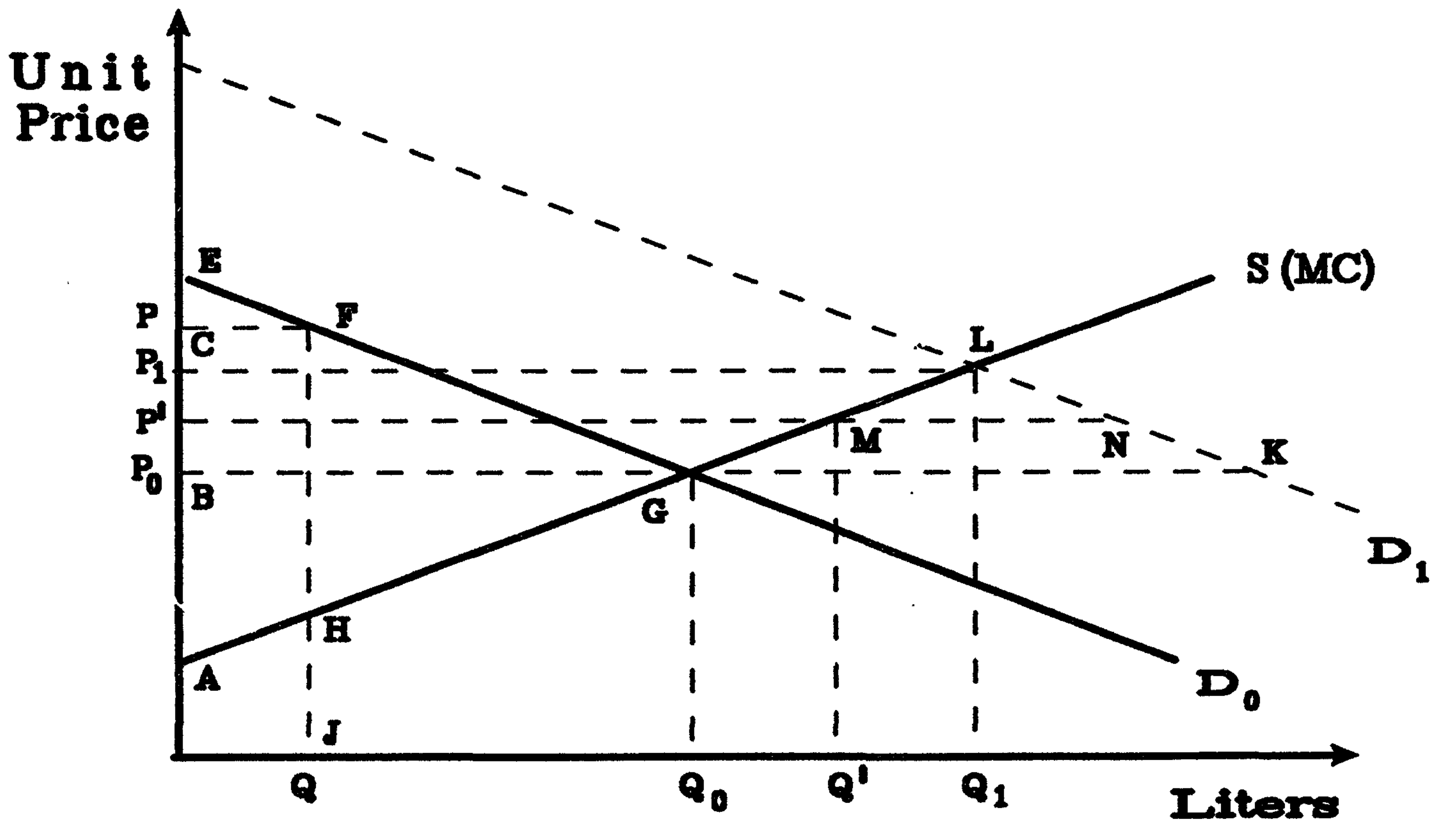
The rationale for setting price equal to marginal cost may be clarified using Fig. 1. Let $EFGD_0$ be the demand curve (which determines the volume of water demanded per year, at any given average price level), while AGS is the supply curve (represented by the marginal cost (MC) of supplying additional units of output).

At the price P, and demand Q, the total benefit of consumption is represented by the consumers willingness to pay, i.e., the area under the demand curve OEFJ, and the cost of supply is the area under supply curve OAHJ. Therefore, the net benefit, or total benefit minus supply costs, is given by the area AEFH. Clearly, the maximum net benefit AEG is achieved when price is set equal to marginal cost at the optimal market clearing point G, i.e., (P_0, Q_0). In mathematical terms, the net benefit (NB) is given by

$$NB = \int_0^Q P(Q)dQ - \int_0^Q MC(Q)dQ$$

where P(q) and MC(q) are the equations of the demand and supply curves, respectively.

FIGURE 1. Supply and demand diagram for water consumption.



Maximizing NB yields:

$$\frac{(d(NB))}{dQ} = p(Q) - MC(Q) = 0$$

which is the point of intersection of the demand and marginal cost curves (P_0, Q_0). Next, we add to this static analysis, the dynamic effect of growth of demand from year 0 to year 1, which leads to an outward shift in the demand curve from D_0 to D_1. Assuming that the correct market clearing price po exists in year 0, excess demand GK will occur in year 1. Ideally, the supply should be increased to Q_1 and the new optimal market clearing price established at P_1. But data concerning the demand curve D_1 may be incomplete, making it difficult to locate the point L.

Fortunately, system data permit the marginal cost curve to be determined more accurately. Therefore, as a first step, the supply may be increased to an intermediate level Q', at the price P'. Observation of the excess demand MN indicates that both the supply and the marginal cost price should be further increased. Conversely, if we overshoot L and end up in a situation of excess supply, then it may be necessary to wait until the growth of demand catches up with the overcapacity. In this iterative manner, it is possible to move along the marginal cost curve towards the optimal market clearing point.

Note that, as we approach the optimum, it is also shifting with demand growth, and therefore we may never hit this moving target. However, the basic rule of setting price equal to the marginal cost and expanding supply until the market clears, is still valid.

Capital Indivisibilities and Peak Load Pricing

Owing to economies of scale, capacity additions to water systems (especially generation) tend to be large and long-lived, resulting in capacity is QM, as shown in Fig. 2, while the optimal price and output combination (P_0, Q_0) prevails, corresponding to the demand curve Do lumpy investments. Suppose that in year 0, the maximum supply and the short-run marginal cost (SRMC) curve (e.g., operating, and maintenance costs).

As demand grows from D_0 to D_1 over time, with capacity fixed, the price must be increased to P_1 to clear the market. When the demand curve has shifted to D_2 and the price is P_2, new plant is added on. Once the capacity increases to Q_n, P_3 becomes the optimal price corresponding to demand D_3 and the SRMC line. Generally, the resulting large price fluctuations over time will be unacceptable to consumers. This practical problem may be avoided by adopting an LRMC approach, as described below.

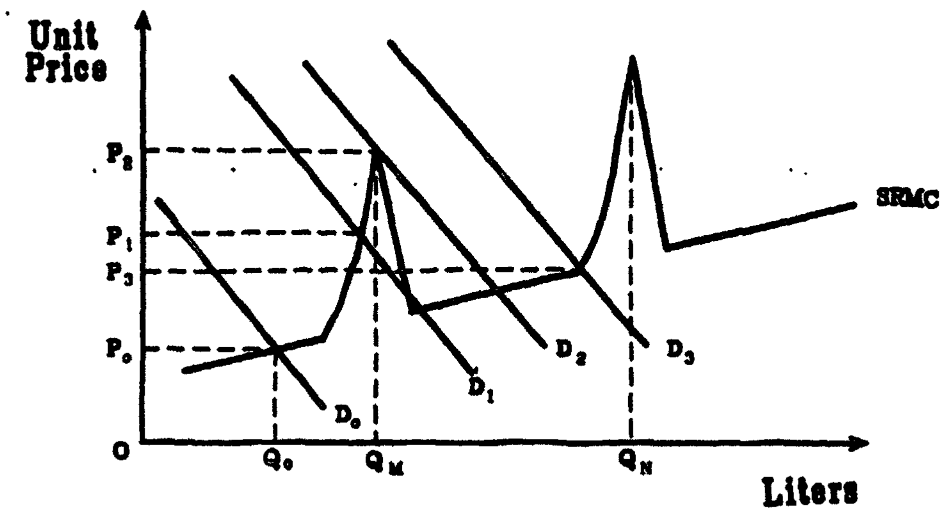


FIGURE 2. The effect of capital indivisibilities on price.

Extensions of Simple Methods

The simplified models presented so far must be extended to analyze the economics of real-world power systems. First, the usual procedure adopted in marginal cost pricing studies may require some iteration as shown in Fig. 3. Typically, a deterministic long-range demand forecast is made assuming some given future evolution of prices. Then, using water system models and data, several plans are proposed to meet this demand at some fixed (target) standard of supply (see below). The cheapest or least cost system expansion plan is chosen from these alternatives. Finally, strict LRMC is computed on the basis of this least cost plan and an adjusted LRMC tariff structure is prepared. If the new tariff that is to be imposed on consumers is significantly different from the original assumption regarding the evolution of prices, however, then this first-round tariff structure must be fed back into the model to revise the demand forecast and repeat the LRMC calculation.

In theory, this iterative procedure could be repeated until future demand, prices, and LRMC-based tariff estimates become mutually self-consistent. In practice, uncertainties in price elasticities of demand and other data may dictate a more pragmatic approach in which the LRMC results would be used after only one iteration to devise and implement new water tariffs. The demand behavior is then observed over some time period; the LRMC

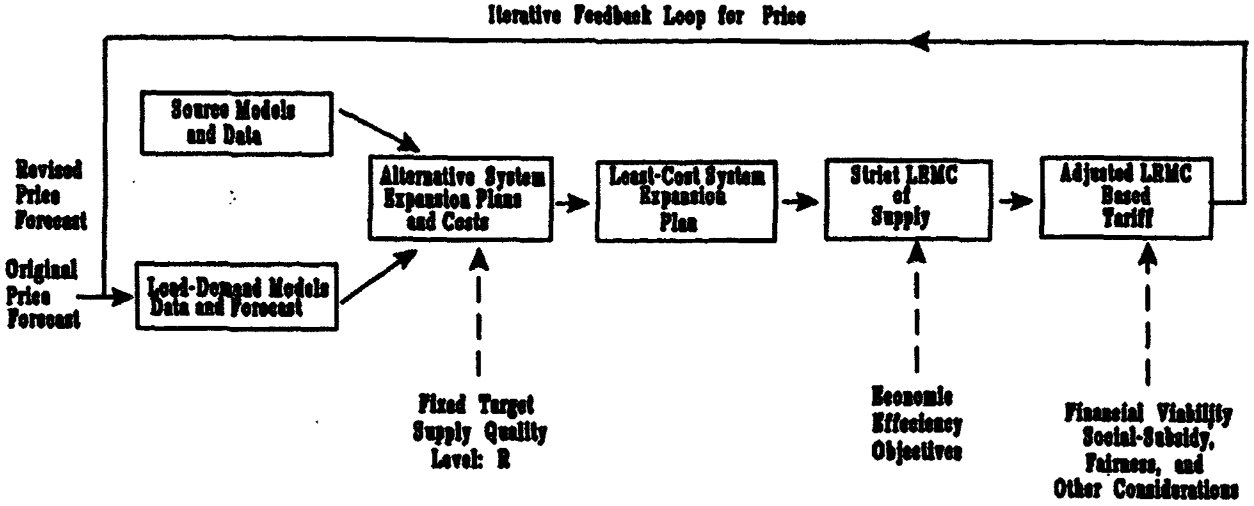


FIGURE 3. The use of price feedback in estimating LRMC based tariffs.

is re-estimated and tariffs are revised to move closer to the optimum, which may itself have shifted, as described previously.

Second, the interrelated issues of supply and demand uncertainty, safety margins, and costs of shortages raise certain problems. Since the least cost system expansion plan to meet the demand forecast is generally determined assuming some (arbitrary) quality of service, the marginal costs depend on this target supply standard.

However, economic theory suggests that service quality should also be treated as a variable to be optimized, and both price and capacity (or equivalently, the supply standard) should be optimized simultaneously. The optimal price is the marginal cost price, while the optimal quality level or standard is achieved when the marginal cost of capacity additions are equal to the expected value of economic cost savings to consumers due to water supply shortages averted by those capacity increments. These considerations lead to a more generalized approach to system expansion planning [9].

Consider a simple expression for the net benefits NB of water consumption, which is to be maximized:

$$NB(D,R) = TB(D) - SC(D,R) - OC(D,R)$$

where TB is total benefits of consumption if there were no shortages or supply failures; SC is supply costs (i.e., system costs); OC is outage costs (i.e., costs to consumers of supply shortages); D is demand; and R is the service quality.

In the traditional approach to system planning both D and R are exogenously fixed, and therefore NB is maximized, when SC is minimized, i.e., least cost system expansion planning. However, if R is treated as a variable:

$$\frac{d(NB)}{dR} = -\frac{\partial}{(\partial R)}(SC+OC)+\frac{\partial}{(\partial D)}(TB-SC-OC).\frac{(\partial D)}{(\partial R)} = 0$$

is the necessary first-order maximation condition.

Assuming

$$\frac{(\partial D)}{(\partial R)} = 0$$

yields:

$$\frac{(\partial SC)}{(\partial R)} = -\frac{(\partial OC)}{(\partial R)}$$

Therefore, as described earlier, the supply quality should be increased by adding to capacity until the above condition is satisfied. An alternative way of expressing this result is that since TB is independent of R, NB is maximized when total costs: TC = (SC + OC) are minimized. The above criterion effectively subsumes the traditional system planning rule of minimizing only system costs, but it raises new problems stemming from the need to accurately estimate outage costs [9].

Shadow Pricing

In the idealized world of perfect competition the interaction of many small profit maximizing producers and welfare maximizing consumers gives rise to market prices that reflect the true economic costs, and scarce resources are efficiently allocated. However, conditions are likely to be far from ideal in the real world. Distortions due to monopoly practices, external economies, and diseconomies (which are not internalized in the private market), interventions in the market process through taxes, import duties and subsidies, etc., all result in market (or financial) prices for goods and services, which may diverge substantially from their shadow prices or economic opportunity costs. Moreover, if there are large numbers of poor consumers, pricing based only on strict efficiency criteria may be socially and politically unacceptable. Such considerations necessitate the use of appropriate shadow prices (instead of market prices) of inputs to the water sector to determine the optimal investment program as well as LRMC [10], [11].

III. CALCULATING STRICT LRMC

Strict LRMC may be defined practically as the incremental cost of optimum adjustments in the system expansion plan and its operation, attributable to a small increment of demand which is sustained into the future. The term long-run incremental cost may also be used interchangeably with LRMC, because the changes refer to small but finite variations. LRMC must be structured within a disaggregated framework, based chiefly on technical grounds. This structuring may include: differentiation of marginal costs by volume of use, geographic area, season of the year, and so on. The degree of structuring and sophistication of the LRMC calculation depends on data constraints and the usefulness of the results, given the practical problems of computing and applying a complex tariff; e.g., in theory, the LRMC of each individual consumer may be estimated. The basic concepts for calculating strict LRMC are summarized below while further details may be found in [10] and [11].

The main categories of marginal costs are: capacity costs, operating costs and consumer costs. Marginal capacity costs are basically the investment costs of new facilities associated with supplying additional water. Marginal operating costs are the costs of providing additional water, with given plant. Marginal customer costs are the incremental costs directly attributable to consumers including costs of hook-up, metering, and billing. Relevant operation and maintenance costs (O&M), as well as administrative and general costs (A&G) may also be allocated to these three cost categories.

Investment Capacity and Operating Costs

Consider the simplified schematic diagram of a typical water supply system shown in Figure 4. Water is produced in bulk (Q_1) at the headworks (point 1) which may consist of dams and reservoirs (surface water) or wells and boreholes (ground water). After treatment (particularly for surface water), the water (Q_2) might typically be transmitted through trunk main pipes (point 2 onwards). Some bulk water consumers may obtain their supplies (Q_B) from the trunk mains. At level 3, the water (Q_3) flows into the primary distribution system -- some of the larger consumers may receive supply (Q_L) at this stage. Finally, the remaining water (Q_4) is piped (level 4) through the secondary distribution systems to reach retail consumers (Q_5) such as households (level 5). Storage tanks, pumping stations and other facilities may also be involved at various points in the delivery system. Water

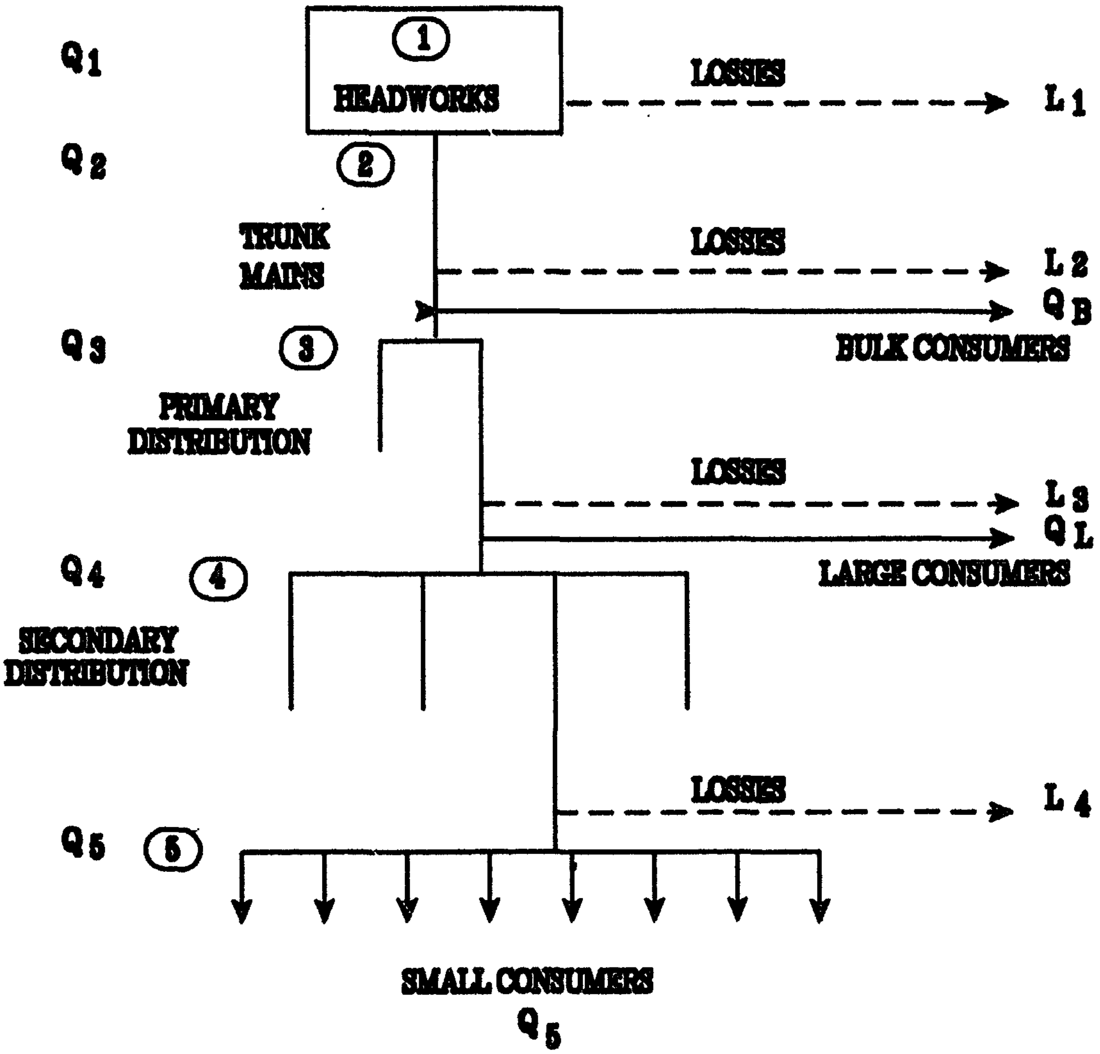


FIGURE 4. Schematic diagram of a typical water supply system.

losses are incurred throughout the system and represented symbolically at the various stages (L_1, L_2, L_3 and L_4).

Figure 5 shows the growth of water produced (AB) to meet rising consumption from initial year 0 to final year T. The upper curve indicates how new facilities are installed at periodic intervals, to ensure that supply capacity is sufficient to meet the demand growth.

Now, we may proceed to estimate the long new marginal cost (LRMC) of water supply. Usually, the average incremental cost (AIC) of supply is a good approximation to LRMC. We may define the average incremental cost of water produced at the headworks by:

$$AIC_H = \left[\sum_{t=0}^{T} \frac{(I_{1t} + R_{1t})}{(1+r)^t} \right] / \left[\sum_{t=0}^{T} \frac{\Delta Q_{1t}}{(1+r)^t} \right]$$

where I_{1t} = investment at the headworks in year t;

R_{1t} = operating and maintenance (recurrent) cost at the headworks in year t;

Q_{1t} = incremental water produced at headworks in year t;

and r = discount rate (e.g., opportunity cost of capital).

Similarly, we may define the average incremental cost of water delivered through the: (a) trunk mains as AIC_T; (b) primary distribution as AIC_P; and (c) secondary distribution as AIC_S.

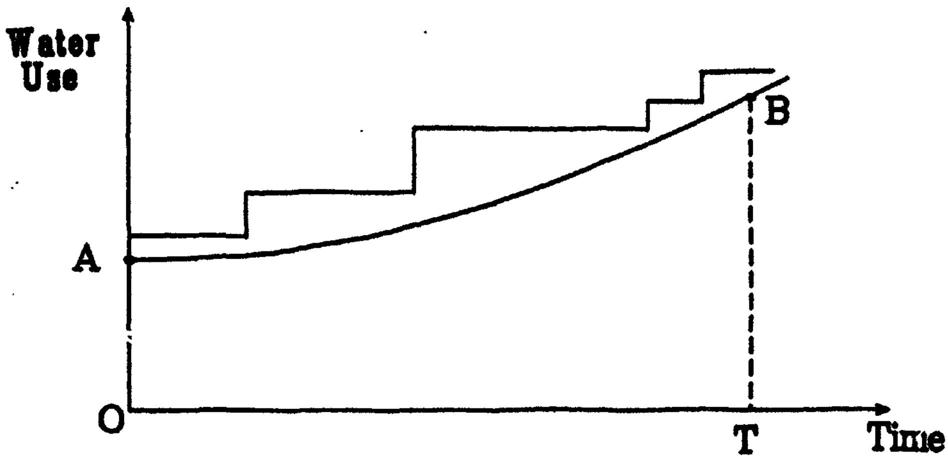


FIGURE 5. Growth of water demand and installed capacity.

If we make allowances for losses, the AIC of water delivered at point 2 is given by:

$$AIC_2 = AIC_H/(1 - LF_1)$$

where LF_1 - $L1/Q_1$ is the loss fraction at the headworks.

Similarly the AIC of water delivered at points 3, 4 and 5 are:

$$AIC_3 = (AIC_2 + AIC_T)/(1 - LF_2)$$

$$AIC_4 = (AIC_3 + AIC_p)/(1 - LF_3)$$

and $$AIC_5 = (AICV_4 + AIC_s)/(1 - LF_4).$$

Customer Costs

Customer costs are defined as those which can be readily allocated to users. Initial customer costs consist of nonrecurrent expenses attributable to items such as the service connection, meter and labor for installation. These costs may be charged to the customer as a lump sum or distributed payments over several years. In some cases the initial costs are treated as a part of the system investment costs and rolled in or absorbed into the average incremental cost per unit of water consumed. In other words, the costs of may be charged to the customer as a lump sum or distributed payments over several years. In some cases the initial costs are treated as a part of the system investment costs and rolled in or absorbed into the average incremental cost per unit of water consumed. In other words, the costs of connecting new water subscribers are distributed over all the water sold.

Recurrent customer costs also occur due to meter reading, billing, administrative and other expenses--these costs could be imposed as a recurring flat charge, in addition to the unit water charges.

Sewerage Services and Externalities

The principles of charging for piped sewerage services are an extension of those we described earlier for piped water supply, since the disposal of liquid wastes through a sewerage system is the logical complement to the provision of water through a sewerage system is the logical complement to the provision of water via household connections. The marginal cost of dealing with waste water can be calculated by using the AIC method, based on investment cost required to conduct sewerage from the consumer through the collection system to the treatment plant (where relevant) and hence back into watercourses. The marginal costs thus calculated can readily be added onto the marginal cost of water supply to obtain a combined charge. However, two particular issues arise which are worth considering.

First, the combined water and sewerage charge is with respect to a joint service and it is conceptually difficult to separate the benefit derived by consumers from each service, or to measure their willingness to pay for water and sewerage separately--since they do not usually face two distinct decisions. This issue is important for investment analysis but is not so critical for pricing purposes. Consumers adjust their consumption of water to the point where, at the margin, they derive a benefit per unit of water used that equals the cost of both supplying and disposing of the water.

Second, externalities are probably much more important in the case of sewerage than water supply. Externalities relate to benefits enjoyed by those other than the water user who actually pays the bill. The aesthetic and health benefits enjoyed by the community at large, due to sewerage service, are obvious and striking. However, this is a matter of degree, because there are also indirect external health benefits enjoyed by the community due to water supply. While consumers should pay the marginal cost of all sewerage disposal wherever possible, there is an economic case for offering some form of subsidy to low-income consumers who cannot take into account the external benefits to the community at large, in their willingness-to-pay decisions (as well as in their ability-to-pay).

Consideration of sewerage charges also leads us logically to the general questions of charging for pollution, but this is too complicated an issue to deal with here.

IV. ADJUSTING STRICT LRMC

Once strict LRMC has been calculated, the first stage of tariff setting is complete. In the second stage, the actual tariff structure which meets economic second best, social, financial, political and other constraints must be derived by modifying strict LRMC. This process of adjusting LRMC will, in general, result in deviations in both the magnitude and structure of strict LRMC. Changes in tariff structure at this stage will be based mainly on sociopolitical factors, e.g., differentiation by type of consumer (residential, commercial, industrial and so on), or by income level (low-, middle-, and high-income residential). Practical considerations such as the difficulties of metering and billing will further affect the final tariff structure.

The constraints which necessitate deviations in the final tariffs from LRMC fall into two categories [11]. The first group consists of distortions which may be analyzed basically within an economic framework, i.e., second best considerations and subsidized (or lifeline) tariffs for low income consumers. In these cases, it is possible to quantify the extent of the deviation from strict LRMC by using an appropriate pricing model and explicit system of shadow prices instead of market prices. The second group includes considerations such as financial viability, sociopolitical constraints and problems of metering and billing where strict economic analysis is difficult to apply. These two groups of constraints may be interrelated, e.g., subsidized tariffs can simultaneously have economic welfare, financial and sociopolitical implications.

Second-Best Considerations

Where prices elsewhere in the economy do not reflect marginal costs, a second best departure from a strict marginal cost pricing policy for electricity services may be required. More generally, price distortions affecting inputs into the production of water, and outputs of other sectors which are highly water dependent, should also be considered. The former type of distortion may be dealt with by direct shadow pricing of inputs as discussed earlier, but the latter case (although quite rare) requires more detailed analysis of the market for the output.

Subsidized or Lifeline Rates

Sociopolitical or equity arguments are often advanced in favor of lifeline rates for potable water supply, especially where the costs of consumption are high in comparison to the relevant income levels. While the ability of water utilities to act as discriminating monopolists permits such tariff structuring, the appropriateness of the lifeline rate policy and the size of the rate blocks requires detailed analysis.

The concept of a subsidized social block, or lifeline rate, for low income consumers has another important economic rationale, based on the income redistribution argument. We clarify this point with the aid of Fig. 6 which shows that respective demand curves AB and GH of low (I_1) and average (I_2) income domestic users, the social tariff Ps over the minimum consumption block O to Q_{min}, and marginal cost based price level P_e. If the actual tariff $P = P_e$, then the average household will be consuming at the optimal level Q, but the poor household will not be able to afford the service.

If increased benefits accruing to the poor have a high social weight or value, the consumer surplus portion FAB should be multiplied by the appropriate social weight (greater than unity). Then, although in nominal market prices the point A lies below P_e, the weighted distance OA could be

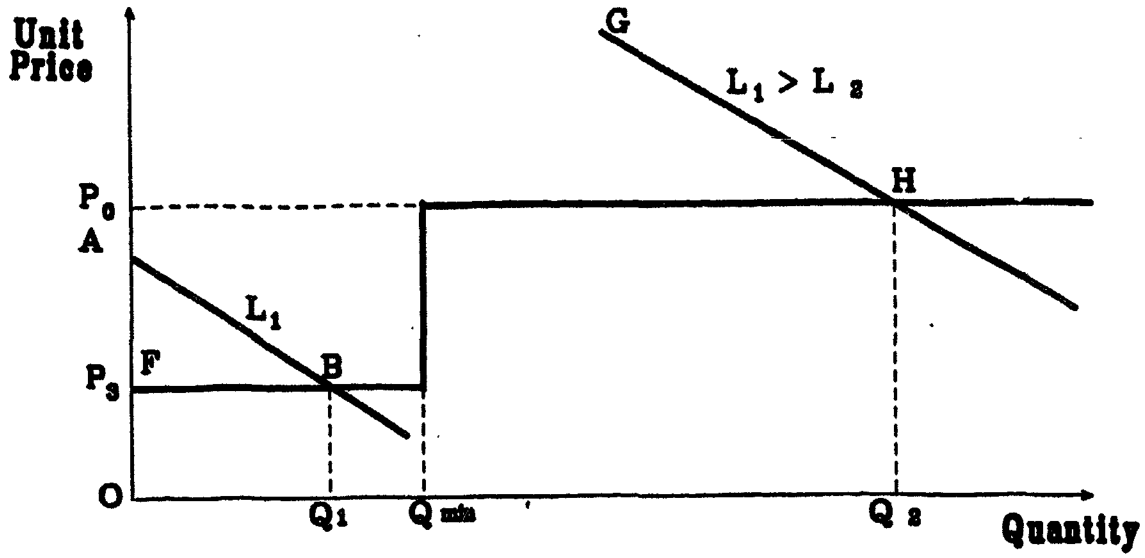


FIGURE 6. Welfare economic basis for the social and lifeline rate.

greater than the marginal cost of supply. The adoption of the increasing block tariff shown in Fig. 6, consisting of the lifeline rate P_s, followed by the full tariff P_e, helps to capture this weighted consumer surplus of the poor user, but does not affect the optimum consumption pattern of the average consumer, if we ignore the income effect due to reduced expenditure of the average consumer for the first block of consumption (i.e., up to Q_{min}). In practice, the magnitude Q_{min} should be based on acceptable criteria for identifying low income groups and reasonable estimates of their minimum consumption levels (e..g, sufficient to supply basic requirements for washing drinking, cooking, etc.). For the price P_s, one simple welfare model yields [11]:

$$P_s = \text{strict LRMC x (poor persons income/critical income)}$$

where the critical income could be some nationally established poverty line (linked, for example, to the official minimum income level). The utility revenue constraints and the ability to pay of the poor consumer would also be considered in determining P_s and Q_{min}. This approach may be reinforced by an appropriate connections policy, e.g., subsidized house connections, especially where the main barrier that poor consumers face is the high initial costs of subscribing to water supply services rather than paying subsequent bills for water use.

Financial Viability

Financial constraints most often encountered relate to the revenue requirements of the water sector, and are often embodied in criteria such as some target financial rate of return on assets, or an acceptable rate of contribution towards the future investment program. In principle, for state-owned water utilities, the most economically efficient solution would be to set price equal to marginal cost and rely on government subsidies (or taxes) to meet the utilities financial needs. In practice, some measure of financial autonomy and self-sufficiency is an important goal for the tor. Because of the premium that is placed on public funds, a marginal cost pricing policy which results in failure to achieve minimum financial targets for continued operation of the water sector, would rarely be acceptable. The converse and more typical case, where marginal cost pricing would result in financial surpluses well in excess of traditional revenue targets, often leads to consumer resistance. Therefore in either case, changes in revenues have to be achieved by adjusting the strict marginal cost based tariffs.

A widely used criterion of financial viability is the utility's potential to earn an acceptable rate of return on assets, for example, the net operating income after taxes given as a fraction of net fixed assets in operation plus, in some cases, adequate working capital. In the case of private utilities--for example, in the U.S.--the regulatory authorities have traditionally imposed a fair rate of return as an upper limit on earnings (and therefore, on average price per unit sold) [7], [14]. Where utilities are government owned, as in most developing countries, the target rate of return is usually considered a minimum requirement to help resist sociopolitical pressures that tend to keep prices too low. If the asset base is defined in revalued terms, then this requirement is more consistent with the forward looking approach of LRMC. Another future oriented financial criteria that is useful, especially when the system expands rapidly, requires the utility to make a reasonable contribution to its future investment program from its own revenues. This self-financing ratio is often expressed by the amount of internally generated funds available after operating expenses and debt service as a fraction of capital expenditures.

The application of these financial criteria often raises serious conceptual and practical problems. Thus, if a rate of return test is to be used, then the question of asset revaluation arises. The use of historical costs for working assets, typically original cost less depreciation, would tend to understate their value when capacity costs are rising rapidly.

If assets are to be revalued, the costs of either (a) exactly reproducing the water system at today's prices; or (b) replacing it with an equivalent system, also at today's prices, might be used after netting out depreciation to allow for the loss of value corresponding to the economic and functional obsolescence of existing equipment.

Significant difficulties of interpretation clearly will occur in the practical application of such approaches.

Whichever criterion or combination of criteria is used, it is important that the initial tariffs based on strict LRMC be included in the utility's financial forecast. Then these first round tariffs may be adjusted through an iterative process until the chosen parameters of financial viability fall within the acceptable range. Although this process is usually quite ad hoc, some practical guidelines may be effectively used for reconciling strict LRMC and the revenue requirement. The relative adjustments to strict LRMC between major consumer categories like residential and industrial, will determine the share of the revenue burden to be borne by each user group.

The simplest practical method of adjustment, which also appears to be the most equitable, is to retain the relative structure of LRMC and vary the average rate level by equiproportional changes. However, in general, this procedure will not be economically efficient.

The application of the Baumol-Bradford inverse elasticity rule whereby the greatest (least) divergence from strict LRMC occurs for the consumer group with the lowest (highest) price elasticity, is the most satisfactory adjustment procedure from the viewpoint of economic efficiency [1]. In the case of two goods, the following expression applies:

$$(1 - LRMC_1/p_1)/(1 - LRMC_2/p_2) = (1/e_1 + 1/e_{12})/(1/e_2 + 1/e_{21}).$$

where $LRMC_i$ and p_i are the strict LRMC and price, respectively, of good i; while

$$e_i = \frac{(\partial Q_i / \partial p_i)}{(Q_i / p_i)}$$

and

$$e_{ij} = \frac{(\partial Q_i / \partial p_j)}{(Q_i / p_j)}$$

are the own and cross price elasticities, respectively, of demand (Q) with respect to price (p). The two goods 1 and 2 may be interpreted as the water consumption of two different consumer groups in the same period of time. In practice, a larger number of consumer types must be considered and application of the rule will be limited by lack of data on price elasticities and the need to use subjective estimates. This technique may appear to penalize some customers more than others, thus violating the fairness objective.

Adjustments involving lump-sum payments and rebates or changes in customer and connection charges are also consistent with economic efficiency, provided consumer water use is relatively unaffected by these procedures, i.e., consumption depends mainly on the variable charges. The magnitude of the adjustments that can be made may be insufficient however. Another related approach for reducing revenues is to charge strict LRMC only for marginal consumption and reduce the price for an initial block of water use. These subsidies on customer charges or on the initial consumption block can also be tailored to satisfy the lifeline rate requirement for poor consumers, but such measure tend to complicate the price structure.

In practice, an eclectic approach involving a combination of all these methods is most likely to be successful.

Other Considerations

There are several additional economic, political, and social considerations that may be adequate justification for departing from a strictly marginal-cost-based tariff policy. The decision to supply water to a remote rural area, which may also entail subsidized tariffs because the beneficiaries are not able to pay the full price based on high unit costs, could be made on completely noneconomic grounds, e.g., for general sociopolitical reasons such as maintaining a viable regional industrial or agricultural base, stemming rural to urban migration, or alleviating local political discontent. While the full economic benefits of such a course of action may be greater than the efficiency costs which arise from any divergence between actual price and strict LRMC, the rationale for such deviation from efficient prices must be thoroughly studied. Pressures to subsidize water supply are likely to be more significant in a developing country than a developed one, because of the high cost of water relative to incomes in the former. Also, the available administrative and fiscal machinery to redistribute incomes, or achieve regional and industrial development objectives by other means, is frequently ineffective in developing nations.

For the same reason, it is particularly difficult to reform pricing policy where low incomes and a tradition of subsidized water supply combine to create extreme sociopolitical difficulties in raising prices to anywhere near marginal costs. In practice, price changes have to be gradual, in view of the costs which may be imposed on those who have already incurred expenditures on equipment and made other decisions, while expecting little or no change in traditional water pricing policies. The efficiency costs of gradualism can be seen as an implicit shadow value placed upon the social benefits that result from this policy. The macroeconomic type argument that water price increases may be inflationary is rarely valid because the costs of water use are usually a small proportion of household expenses and of industrial production costs. In contrast, the overstimulation of demand and lack of funds to expand supply, resulting from low water prices are potentially much more serious long-run problems that should not be ignored.

Metering, Billing and Customer Comprehension

Owing to both the practical difficulties and the economics of metering and billing, the tariff structure may have to be simplified. Another crucial factor is that the tariff structure must be comprehensible to the average customer. Otherwise, individuals will not be able to adjust their consumption according to the price signals. Therefore, the number of customer categories, consumption blocks, and fixed charges will have to be limited.

The degree of sophistication of metering depends on the practical problems of installation and maintenance, and the net benefit of metering (based on a cost benefit analysis that compares the lower supply costs of reduced consumption with the cost of metering plus the decrease in net consumption benefits) [11].

Recently, advanced solid-state technology (including use of microprocessors) is being examined to implement sophisticated metering, automatic meter reading, load management techniques and pricing structures. In contrast, some developing countries may lack technically skilled labor for installation and maintenance of sophisticated meters, or even reliable meter readers. Therefore, choice of appropriate metering is usually very country specific, and is likely to involve many practical considerations.

V. PRACTICAL IMPLEMENTATION AND MODERN PRICING STRUCTURES

In this section we briefly review the types of tariff structures used to implement the LRMC approach and their relative effectiveness.

Over the last few decades, price structures have become increasingly complex as both the techniques for analyzing the structure of supply costs and the metering hardware available to apply these tariffs have become progressively more sophisticated. Since the quantity, quality and price of water supplied to each consumer can be, if necessary, individually controlled or at least monitored, a high degree of discrimination and structuring is possible with water prices. In theory, a separate tariff could be devised for each customer. In practice, however, as discussed in the previous section, the complexity of the tariff would be limited by the metering capabilities, the problems of billing, and the ability of water users to comprehend and react to the price signals provided by the utility.

The structuring of LRMC with respect to location and customer type have been discussed earlier. This section focuses on how tariffs may be devised and implemented, that vary in relation to the water consumption or include fixed charges (both nonrecurrent and recurrent). Structuring of these aspects by time of use (e.g., season) and usage level will also be reviewed. These basis building blocks may be combined in various ways to yield many different types of tariff structures differing in their finer details.

One common form of tariff is the unit charge based on the customer consumption over a given period of time, typically one month. (It is interesting to note that in the case of electricity, meters that record consumption continuously over shorter periods may be used to implement short-term prices that vary by time of use.)

Unit charges may also be varied according to the volume of water consumed, yielding two basic types of block tariff structures. Incorporation of the increasing block structure in applying the LRMC-based methodology has already been discussed, particularly in the section on social or subsidized prices.

The decreasing block tariff, in which the initial slab of consumption has the highest price followed by successively cheaper blocks has been widely used especially for households and small consumers with simple metering. The rationale for this policy included arguments that: (a) the utility could recover some of the fixed customer costs through the high priced initial block even though water consumption was low; (b) the first block corresponded to the high cost of supplying the customers during peak period for water demand, whereas additional consumption was mainly caused by off-peak appliance use that could be supplied at relatively low cost; (c) the utility should encourage increased consumption to realize economies of scale in production; (d) price discrimination could be used to extract the maximum revenue from smaller users who had low price elasticities of demand while also encouraging consumption of larger users who were more sensitive to high prices; and (e) if temporary excess capacity existed--for example, when new plants are developed--higher consumption should be encouraged to collect the maximum potential revenues.

All of these arguments ignore the fact that if any portion of the decreasing block tariff is significantly below LRMC, it signals the consumer that water is much cheaper than it really is, thus encouraging wasteful consumption. A more appropriate pricing policy recognizes at least the following. First, if customer costs must be recovered then single or recurring fixed charges should be used. Second, unless there is clear evidence that customers with greater consumption (in a given user category) impose lower costs on the system, any additional water consumed by all consumers will be equally costly to supply. Therefore, there would be little basis for price discrimination according to consumption level. Third, even if economies of scale exist at the aggregate level of the utility, they do not apply in the case of the variable costs to individual customers. In fact, few utilities currently exhibit any economies of scale, and real unit costs of supply in the long run are rising. Fourth, it must not be generally assumed that the consumption of larger users would be more sensitive to price. Fifth, using up any short-run excess capacity is not costly in the long run, because if demand growth is unduly stimulated, investments in capacity expansion must be advanced. Finally, the decreasing block rate tends to be regressive and unfair, because it penalizes poorer consumers who generally use less but must pay higher prices per unit purchased (see also, earlier discussion of lifeline tariffs).

Fixed charges are most often related to consumer costs as described earlier. A lump-sum payment may be levied to cover the initial cost of providing the service connection, or the repayment period may be spread over several years to provide relief to customers. Recurrent fixed costs are charged to meet the costs of meter reading, billing, and other repetitive expenses. In some cases, the charge based on the capacity of a consumer's connection is also called a fixed charge, but this is usually a proxy for the capacity cost which should be included in the variable charge.

Surcharges or adjustment clauses are also becoming increasingly common. This permits the utility to quickly pass on to the consumer any unforeseen increases in operating costs. Ideally, any changes in relative input prices would require reestimation of strict LRMC followed by changes in the tariff structure, but the legislative procedure to achieve the latter may take a long time. A convenient short-run adjustment clause can, meanwhile, provide much needed financial relief when cost inflation is significant [11].

REFERENCES

[1] W.J. Baumol and D.F. Bradford, "Optimal departures form marginal cost pricing," Amer. Econ. Rev., pp. 265-283, June 1970.

[2] M. Boiteux, " La tarification des demandes en pointe," Rev. Gen l'Electricite, vol. 58, 1949.

[3] M. Boiteux and P. Stasi, "The determination of costs of expansion of an interconnected system of production and distribution of electricity," in J. Nelson, Ed., Marginal Cost Pricing in Practice. Englewood Cliffs, N.J.: Prentice-Hall, 1964.

[4] M. A. Crew and P. R. Kleindorfer, Public Utility Economics. New York: St. Martin's PRess, 1979.

[5] A. Donziger, "The underground economy and the theft of utility services," Public Utilities Fortnightly, pp. 23-27, Nov. 22, 1979.

[6] P. Dupuit, "De l'Utilite' et de sa Mesure," La Reforma Soziale. Turin, Italy, 1932.

[7] P. J. Garfield and W.F. Lovejoy, Public Utility Economics. Englewood Cliffs, NJ: Prentice Hall, 1964.

[8] H. Hotelling, "The general welfare in relation to problems of taxation and of railway and utility rates," Econometrica, vol. 6, pp. 242-269, July 1938.

[9] M. Munasinghe, Economics of Power System Reliability and Planning. Baltimore, MD: John Hopkins Press, 1979.

[10] M. Munasinghe and J. J. Warford, "Shadow pricing and the evaluation of public utility projects, World Bank, Washington, D.C., 1977.

[11] M. Munasinghe and J. J. Warford, Electricity Pricing. Baltimore, MD: John Hopkins Press, 1981.

[12] N. Ruggles, "The welfare basis of the marginal cost pricing principle," Rev. Economic Studies, vol. 17, pp. 29-46, 1959.

[13] N. Ruggles, "Recent developments in the theory of marginal cost pricing," Rev. Economic Studies, vol. 17, pp. 107-126, 1959.

[14] J. Suelflow, Public Utility Accounting: Theory and Applications. East Lansing, MI: Michigan State Univ., 1973.

[15] P. Steiner, "Peak loads and and efficient pricing," Quart. J. Econ., Nov. 1957.

[16] Symposium on Peak Load Pricing, Bell J. Economics, vol. 7, pp. 197-250, Spring 1976.

[17] R. Turvey and D. Anderson, Electricity Economics. Baltimore, MD: Johns Hopins Press, 1977.

[18] J. T. Wenders, "Peak load pricing in the electric utility industry," Bell J. Economics, vol. 7, pp. 232-241, Spring 1976.

[19] O. E. Williamson, "Peak load pricing and optimal capacity under indivisibility constraints," Amer. Econ. Rev., vol. 56, pp. 810 -827, Sept. 1966.