WATER PRICING MODELS: A SURVEY

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Water Pricing Models: a survey*

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Abstract

This paper surveys water pricing models, highlighting some important results. Efficiency requires marginal cost pricing. Intra-annual price changes or customer differentiation to reflect differences in marginal costs can enhance efficiency. A marginal cost pricing mechanism may signal the value that consumers attribute to further capacity expansions as the water supply system approaches its capacity limit and marginal cost rises. However, pure marginal cost pricing may not be feasible while respecting a revenue requirement because marginal costs may be higher or lower than average costs. The most common ways of combining efficiency and revenue requirements are through the use of two-part tariffs, adjusting the fixed charge to meet the revenue requirement, or through second-best pricing like Ramsey pricing. It is not evident whether the best scheme is a two-part tariff or some other pricing mechanism. The role of block rate pricing, increasingly more frequent in actual pricing practices, is yet to be fully investigated.

Keywords: water pricing models; capacity constraints; scarcity; revenue requirements; second-best pricing; block rate pricing

JEL Classification: L95, Q25.

1. INTRODUCTION

There is an abundant literature on water pricing. Several studies on the impact of the water price on water demand are published every year. Articles comparing the properties of different price schemes or pointing out the difficulties in implementing more efficient pricing rules are also frequent, with a diversity of case studies on implementing water pricing reforms. However, theoretical water pricing models are scarcer and more disperse in the scientific literature. They are important to the water utility manager or to the water supply industry regulator who have to present precise water pricing schemes to customers in the specific conditions they operate in. Furthermore, the Water Framework Directive approved in 2000 requires that by 2010 (art. 9, n. 1) a price policy must be defined not only to recover the costs of the resource, but also to provide incentives for consumers to use water efficiently, contributing to the established environmental targets. This paper attempts a systematic review of the existing literature on water pricing models. Most issues dealt with here are not specific to the water sector. Marginal cost pricing (Dupuit, 1844; Coase, 1946 and 1970), capacity constraints and peak-load pricing (Boiteux, 1949), revenue requirements (Allais, 1947) and nonlinear pricing (Wilson, 1997) are subjects which have been researched in the more general framework of regulated public utilities for a long time now. (Brown and Sibley, 1986) present the first systematic exposition of the previous contributions to the theory of public utility pricing.

2. EXISTING WATER PRICING SCHEMES

There is a bewildering diversity of actual water prices and rate structures implemented by different water utilities, even within areas where geographical conditions are similar.

The customer may be required to pay a connection fee to gain access to the water supply system. A service charge is often required to cover costs that are not related to the quantity consumed (like metering cost; in fact, service charges are also frequently called meter charges) or to guarantee cost recovery in situations where price differs from average cost.
A quantity-related price is a consensual requirement for efficiency but in reality volumetric pricing can be implemented in a variety of ways. The utility may implement an uniform rate, which in turn can be based on the average or on the marginal cost of water supply. This uniform price may be combined with rebates or discounts to assure that no excessive profits are generated in the cases where marginal cost related prices exceed average costs. Another frequent solution is the implementation of nonlinear pricing with block tariffs (tiered pricing). Decreasing block tariffs may be supported where a natural monopoly is recognized, while increasing block tariffs are often associated with the implementation of marginal cost pricing with equity or poverty alleviation concerns, or simply to signal potential scarcity or capacity constraints.

Other possible variations are the differentiation of price structures according to customer classes or seasons. Even the adoption of time-of-day pricing has been advocated for the water industry, although it is more frequent in the electric power industry.

A frequent solution is the adoption of a two-part tariff, which consists in the combination of a service charge with an uniform volumetric price, but other water pricing and allocation methods are possible.

Surveys of water pricing schemes and water rates are often published by the national institutes concerned with the environment in general or the water industry in particular. A few examples can be pointed out:
- in 1999, the American Water Works Association surveyed the financial and revenue information of 671 US and Canadian water utilities, including their water pricing practices;
- in 2002, the U.S. Environmental Protection Agency published the report "2000 Community Water Systems Survey" with operating and financial information for approximately 2000 water utilities in the USA;
- in the same year, Raftelis Financial Consulting, PA published the report "RFC 2002 Water and Wastewater Rate Survey" for 167 US service areas, 6 Canadian cities, and 8 international cities;
- the Portuguese National Water Institute (INAG) is currently making public the results of its National Survey on Water Supply and Wastewater Systems (INSAAR), which includes data on the water pricing schemes implemented.

Studies on actual water pricing schemes are also available. For example, (Hewitt, 2000) describes the pricing methodology supported by the American Water Works Association (AWWA), (Garcia and Reynaud, 2004) describe the French water sector, (Howe, 2005) describes the water pricing institutions in the United States and in Canada and (Garrido, 2005) surveys the major case studies and practical applications of water pricing in Brazil. Other case studies for specific countries are often to find.

3. WATER PRICING MODELS

The articles surveyed present theoretical water pricing models which concentrate on particular questions of water pricing. The questions addressed are varied and numerous. Table 1 sums up the main ones and the papers that deal with each one.

Table 1. Questions addressed by the water pricing models

Questions addressed	**Articles**
Average vs. Marginal Cost Pricing	Hirshleifer et al., 1960 Ryordan, 1971 Dandy et al., 1984 Zarnikau, 1994 Chambouleyron, 2003
Seasonal or temporal variations	Gisy and Loucks, 1971 Riley and Scherer, 1979 Manning and Gallagher, 1982 Dandy et al., 1984 Zarnikau, 1994 Elnaboulsi, 2001 Schuck and Green, 2002
Capacity constraints or expansion decisions (Peak-load pricing)	Hirshleifer et al., 1960 Ryordan, 1971 Gysi and Loucks, 1971 Riley and Scherer, 1979 Manning and Gallagher, 1982 Zarnikau, 1994 Elnaboulsi, 2001 Griffin, 2001
Scarcity	Moncur and Pollock, 1988 Zarnikau, 1994 Elnaboulsi, 2001 Griffin, 2001 Schuck and Green, 2002
Revenue requirements	Hirshleifer et al., 1960 Freedman, 1986 Collinge, 1992 Zarnikau, 1994 Kim, 1995 Griffin, 2001 Schuck and Green, 2002
Optimal number of metered connections	Barrett and Sinclair, 1999 Griffin, 2001 Chambouleyron, 2003
Efficiency of block tariffs	Gisy and Loucks, 1971 Elnaboulsi, 2001
Second-best pricing	Kim, 1995 Elnaboulsi, 2001 Schuck and Green, 2002
Optimal derivation of nonlinear pricing schemes	Elnaboulsi, 2001
Customer heterogeneity	Elnaboulsi, 2001 Chambouleyron, 2003

Storage	Riley and Scherer, 1979 Manning and Gallagher, 1982
Groundwater	Moncur and Pollock, 1988 Schuck and Green, 2002
Conjunctive use of surface and groundwater	Schuck and Green, 2002
Utilization of water as an input	Schuck and Green, 2002
Constraints regarding water price changes	Dandy et al., 1984
Pricing of wastewater services	Elnaboulsi, 2001
Multi-product water supply	Kim, 1995
Dynamic programming techniques	Ryordan, 1971 Gysi and Loucks, 1971 Riley and Scherer, 1979
Simulation techniques	Schuck and Green, 2002
Discounting	Manning and Gallagher, 1982

We now present the listed articles in greater detail, focusing on the most important issues refered to in table 1.

3.1 Average vs. Marginal cost pricing

The oldest debate in the literature on water pricing is whether to price water by its average cost (based on financial reasons of cost recovery) or by its marginal cost (based on the economic reasoning of promoting an efficient use of the resource). As we will see, this is a closed debate by now, if not in actual practices, at least among economists.

Essentially, a resource is considered to be used efficiently if the benefit for society from consuming the last or marginal unit of the resource is the same as the cost of obtaining it (including the opportunity cost of foregoing other alternative uses). If the price of the resource is equal to its marginal cost, then the consumer can adequately compare the benefits she obtains with the costs she imposes with her consumption decision. If the unit price differs from marginal cost consumption levels will be either too high (for prices below marginal costs) or too low (for prices above marginal costs) in relation to the socially optimum level of consumption.

(Hirshleifer et al., 1960) support the use of marginal cost pricing of water, opposing the practices of average cost pricing, for the efficiency reasons mentioned above. They also support price differentials for on-peak and off-peak demand. For example, seasonal peaks in water demand in the summer would require the introduction of a summer peak-load differential or surcharge in price. This question is dealt with in further detail in the next section.

(Riordan, 1971b) compares typical average cost pricing techniques with her proposal of multistage marginal cost pricing. She finds that the latter is able to provide a 10-20% increase in total net benefits.

(Dandy et al., 1984) analyze a constrained water pricing method (where there are constraints on the magnitude of price changes allowed in a change from average cost pricing to an optimal marginal cost pricing rule). They find that such a scheme, while being less efficient than the optimal water pricing derived in their model, can still increase benefits to society when compared to actual average cost pricing practices.

(Zarnikau, 1994) develops a model of spot market pricing for water (short-run marginal cost pricing), based on previous work done for the electric power industry. Again, this water pricing system is more efficient than average cost pricing, especially when short-run marginal costs vary over time or when water becomes scarce and rationing methods have to be found. This system would also provide information about the customers' valuation of system enhancements or capacity increases through the amounts they actually pay when capacity constraints are binding.

(Chambouleyron, 2003) compares both pricing schemes under different metering regimes (universal metering and optimal metering). He also shows that marginal cost pricing is always the most efficient pricing regime.

3.2 Seasonal or temporal variations

Having seen that marginal cost pricing is common sense in the literature nowadays, the next question is how to deal with time-related variations of marginal cost and whether they should be reflected in the water price.

(Gysi and Loucks, 1971) extend the analysis made by (Riordan, 1971a) about the investment-pricing decisions of a monopolistic public utility by considering block rate water tariffs and seasonal variations in prices. They disaggregate nonlinear demand functions for five residential sectors. Their results point out the advantages of an increasing block rate schedule combined with a summer price differential.

The spot-market pricing system developed by (Zarnikau, 1994) derives prices that vary with location and time (including time of day). Some additional charges may be customer specific. Short-run marginal costs must include, besides operating costs, the costs imposed by capacity constraints or by the scarcity of water resources, to ration the available water to the highest value uses.

The author also points out some questions regarding an actual implementation of the system. Additional charges related with capacity constraints or water scarcity should be set at a level which assures that existing demand at such prices can be met by the existing water supply. This requires the knowledge of the price-elasticity of demand. Price changes would be very frequent (including different charges for different periods of the day with frequent price changes in a single day). However, such frequent changes may cause instability in the long-term decisions of customers like investing or not in water saving technologies. The author does not address this issue. The adoption of this kind of pricing system would require the implementation of a communications system to keep customers permanently informed of the possibly frequent price changes, as well as more frequent meter readings, possibly through remote meter reading technology using telephone lines or cable television. Consumers are expected to respond to time-of-day-pricing or spot market pricing by changing their consumption from periods with higher prices to periods with lower prices.

Finally, it should be noted that the model developed by (Zarnikau, 1994) ignores the implementation costs of this water pricing system. For a spot-market water pricing system to be worth implementing its benefits must outweigh its costs. The author uses an analogy with implementation practices in the electric power industry to suppose that it might only be beneficial to implement this water pricing system in the class of large water users such as industrial or commercial users or golf courses. The residential class could remain with other more traditional water pricing systems. For this dual pricing system to be effective, curtailment premiums (additional charges due to capacity constrains or scarcity) imposed on large users would have to be overstated, because residential customers would not be given the same price signals.

(Schuck and Green, 2002) develop a model of water pricing with the ability to reflect variations in water supply on the price of water (supply-based water pricing model) and to consider the revenue constraints of the water providing agency. It does so in the context of a conjunctive use system with stochastic surface water flows. The model combines the techniques of conjunctive use systems management and second-best (Ramsey) water pricing. It considers the case where water is an input in the activity of farmers, and it also allows for the possibility of recharging the aquifer with excessive surface water in bountiful years, although not without a cost. The authors assess the impact of the pricing policy on water use, acreage (land use) and energy use, through an application to a water district from California using simulation techniques.

The social planner's model that is developed indicates the existence of a U-shaped cost curve with higher cost in times of drought (due to pumping costs) and times of plenty (due to recharging costs). They conclude, however, that while the pumping costs incurred by the irrigation district in periods of drought should be added to the remaining usual costs in average supply periods, the recharging component of the costs should be subtracted from the remaining costs in the determination of the water price to encourage growers to use more surface water. This would avoid the costs of recharging the water in the aquifer. This argument seems to make sense at first, but the fact that it is not mathematically consistent with the cost equations and the marginal cost pricing rule raises the question of its actual correctness. Maybe the argument is erroneous in thinking only in the short-term. The problem in the paper is one of dynamic optimization, therefore, the short-term argument that the irrigation district will try to avoid the cost of having to recharge the aquifer in times of plenty, may be wrong because it is not considering the value in the future of having water in the aquifer to pump in times of drought. By introducing the possibility of recharging the aquifer, the authors created also a storage problem that is not entirely dealt with in the paper. Notice that, instead of recharging and facing the corresponding costs, the district could waste the excessive water, thus not needing to lower the price to avoid the recharging costs! The problem in this paper is twofold: recharging the excessive water is faced as an obligation and not as a possibility; in the recharging decision the authors are only considering the present costs and not the future value of greater aquifer height (reducing future pumping costs in periods of drought).

The results indicate that the adoption of the supply-based pricing policy proposed reduces water demand and energy use and increases fallowing (leaving the land uncultivated) in periods of drought, adjusting agricultural activities to the water supply of each period. However, future research would have to validate these conclusions after correcting for the problem mentioned above and considering the value of storage in smoothing water supply over time. The development of this kind of seasonal water pricing methods must take explicitly into account the possibility of water storage.

3.3 Capacity constraints or expansion decisions

The determination of water price when facing capacity constraints has been an issue of research for a long time now, not only for water supply, but also for other public utilities like electric power supply. This decision is usually studied together with the decisions to expand the system. One important conclusion is that peak-load pricing may delay investment in system expansion in relation to other more inefficient pricing schemes.

(Riordan, 1971a) develops a model of optimal water pricing and investment by a publicly owned or regulated monopoly called multistage marginal cost pricing. The model is based on a short-run marginal cost pricing rule. When supply approaches capacity the price necessarily rises, keeping demand within capacity constraints. Dynamic programming techniques are employed to derive the optimal capacity expansions and their adequate timing. (Riordan, 1971b) applies the model to urban water supply treatment facilities.

(Riley and Scherer, 1979) deal with the issue of peak-load pricing when supply and demand are both seasonal and there is the possibility of storage. They apply it to water pricing where seasonal supply and demand are out of phase. The article combines the literatures of peak-load water pricing and reservoir planning and operation.

(Manning and Gallagher, 1982) extend the model developed by (Riley and Scherer, 1979) to treat two additional problems ignored in the latter article: the importance of discounting (time preferences) to pricing policies and the derivation of an optimal discrete approximation to optimal continuous pricing policies. To do so they use the concept of arbitrage between different periods of time enabled by water storage. The arbitrage possibility is not so much based on the stochastic nature of water inflow, they argue, but more on its seasonal pattern. Arbitrage would be profitable in periods when there is an increase of the natural price of water (the price that continuously equates time varying supply and demand). Water storage would be more worthwhile the more price-inelastic is the demand for water.

They find that, in the absence of storage capacity limits and direct costs of water storage (other than the opportunity cost of keeping the water in storage instead of selling it), the price of water held in storage must rise at the rate of interest and the effect of discounting is to cause a cycle in the price of water (the initial price of water is set to equate total water inflow and total water demand over the cycle). If $p(t_1)$ is the price at which we could be selling an additional unit of water at time t_1, $p(t_2)$ is the price at which we will be able to sell it at time t_2 if we keep it in storage from t_1 to t_2, and r is the interest rate, then is must be that $p(t_2) = p(t_1)e^{r(t_2 - t_1)}$, otherwise arbitrage would be possible between the two periods (remember it has been assumed there were no direct storage costs).

The authors consider that the rule created by (Hotelling, 1931) for the optimal price of an exhaustible resource available in a fixed quantity is just a limit case of the kind of storage problem they face, with the inflow of resource limited to an initial endowment in the first period and with no limit on the ability of storage capacity to carry this quantity over to the following periods.

The authors also find that if there are limits to storage capacity, water prices can rise faster than the interest rate when the capacity constraints are binding (when the water storage facilities are full). The optimal water storage capacity derived will depend negatively on the price-elasticity of demand and positively on the planning horizon length.

The model developed by (Dandy et al., 1984) to determine optimal water pricing and optimal magnitude and timing of capacity expansions is an extension of the work done by (Hirshleifer et al. 1960) and (Riordan, 1971a). As mentioned above, they consider also the political feasibility of the optimal rule derived.

3.4 Scarcity

Scarcity is a more recent concern than capacity constraints, reflecting the fact that the usual approach to rising water demand in the past was to expand the water supply system.

(Moncur and Pollock, 1988) deal with the problem of determining the scarcity rent of water. They consider the case of a water utility with groundwater as its only source, and use a nonrenewable resource efficient extraction model to determine the scarcity value and the efficient path of price in the future. They calculate the scarcity value through the consideration of the future increase in costs originated by the necessity to use costly backstop technologies (such as desalination or trans-basin diversions) to satisfy water demand. They apply their model to Honolulu and find the scarcity value to be approximately twice the current water charge. An efficient price would have to equal marginal cost and the latter should include not only accounting costs but also opportunity costs reflected in the scarcity rent for water. This implies that efficient pricing of water in Honolulu would require its current price to triple.

(Elnaboulsi, 2001) uses a constraint on the water available which, when binding, allows the determination of the shadow value of water resources. This opportunity cost is reflected in the price charged.

(Griffin, 2001) demonstrates that the price should also include nonaccounting opportunity costs such as: marginal value of raw water (surface and fully renewable ground water sources, in scarcity situations); marginal user cost (to take into account the sacrifice of future uses in unrenewed groundwater supplies); marginal capacity cost (when the water supply enabled by the capacity installed is less than the water demand).

3.5 Revenue requirements

Marginal cost pricing does not ensure that the water utility generates enough, and just enough, revenues to cover costs (including a reasonable amount of profit to guarantee the involvement of private firms in the industry). Some authors, like (Zarnikau, 1994), warn us that marginal costs may fall below average costs, which is the situation to be expected in capital-intensive industries like water supply. Others, like (Collinge, 1992) point out that despite the fact that water utilities are commonly viewed as a natural monopoly due to capital costs, it is not straightforward that the marginal cost falls below the average cost. Because cheaper sources of water are naturally used before other more expensive sources, marginal cost can rise above the average cost of water supply. Therefore, marginal cost pricing can raise a problem to the water utility and its regulators, not because of insufficient revenue, but because it would generate excessive profits. Using marginal cost pricing in a situation where average cost is lower than marginal cost can be an efficient way to raise revenues. Nevertheless, it is generally not allowed, namely because it has a "regressive incidence", hurting the poor the most, since water expenses have a greater weight in their budget. Balancing the budget of the water utility is therefore an objective on the same level of importance as achieving economic efficiency.

(Hirshleifer et al. 1960) consider five alternatives to ensure financial viability of water utilities which adopt marginal cost pricing in a situation of natural monopoly (with declining average costs): government subsidies; voluntary contributions from customers to ensure water supply; declining block-tariffs; two-part tariffs; separation of customer classes which face different prices (not all necessarily equal to the marginal cost). The authors favour the adoption of declining block tariffs first and two-part tariffs as a second choice.

(Freedman, 1986) develops a model with the aim of keeping the water utility's budget close to zero. Although the title claims this is an article on water pricing, in fact the models developed only deal with the profit the water utility should target in each year, saying nothing about the prices or tariff structures it should implement to reach the intended profit.

(Collinge, 1992) proposes a solution to price water efficiently without generating excessive profits for the water utility or excessive burdens for the consumers. The proposal is based on a system of tradable discount coupons ("marketable rights to buy water at prices below marginal replacement costs") with expiration dates, issued by a single water supplying agency. They give the consumer a discount with a value equal to the difference between the marginal and the average cost of water supply (assuming that the average cost falls below the marginal cost). One of the biggest advantages of this proposal is the fact that it only requires information about the cost of existing and additional supply sources, without requiring information on consumer demand (this is a general advantage of water trading schemes). Moreover, the implementation of marginal cost pricing would ensure efficiency, while the issuing of a limited number of discount coupons could balance the water utility's budget.

(Zarnikau, 1994) mentions some other measures pointed out in the literature to fulfill the revenue requirement, even if sacrificing efficiency in part. These measures are to add (or subtract) a fixed charge to the water bill, to multiply the prices by a fixed factor or to adjust the prices in inverse proportion to the customer's price elasticity of demand. The latter is called Ramsey pricing. When average price is higher than marginal price, the remaining revenue, not ensured by marginal cost pricing is obtained in this method through additional charges/higher prices on the customers with less elastic demand functions.

(Kim, 1995) derives second-best optimal prices for water supply by a water utility with two products: residential water and nonresidential water. A second-best Ramsey pricing rule is used to assure the balancing of the supplier's budget. The author associates the estimation of a translog multiproduct joint cost function for the water supply industry with given price elasticities of demand for both products, avoiding a simultaneous estimation of both the demand and supply functions.

The results point to a higher price for residential water, which has a lower price elasticity of demand, therefore the budget balancing task falls mainly on residential users. The actual prices are found to be close to the second-best prices derived in the article (no more than a 10% increase in prices would be needed to turn actual prices into second-best prices). The author also finds some evidence of the existence of economies of scope.

(Griffin, 2001) proposes a tariff structure for water that aims both at efficiency and revenue neutrality of the water utility. He focuses on water supply, setting aside the issues of wastewater, reliability, peak loads, different customer classes, different service capacities and seasonality. The author examines three type of decisions: water consumption by each customer; continuation of service by existing customers; enrollment decisions by prospective new connections. For each of these decisions the author derives the efficient level, which maximizes the present value of net social benefits.

Afterwards, the author proposes a rate structure that achieves these efficient levels while keeping the utility's budget balanced. The rate structure consists of a two-part tariff with a fixed meter charge per period plus a volumetric charge based on the marginal cost of water to achieve efficiency. A connection fee is also charged. In order to achieve revenue neutrality, a water consumption threshold is determined. Consumption below the threshold generates a credit to the consumer that may turn into a payment to the customer if the credit exceeds the meter charge. The correct parameterization of the threshold (and remaining price-related parameters) enables the balancing of the budget.

The author claims that the tariff structure he proposes is more general than the usual two-part tariff because: it does not assume a structure for the cost function (decreasing or increasing); it separates the problems of efficient allocation of water resources and nonwater resources (associated with distribution and metering).

3.6 Metering

(Barrett and Sinclair, 1999) investigate whether the policy of allowing households to choose if their water consumption will be metered is optimal or not. This policy has been adopted by some countries like the United Kingdom. In their model, the authors also determine optimal water volumetric and fixed charges. The authors conclude that it may be efficient not to meter every customer and to have a dual system where the customer chooses if he should be metered or not (with nonmetered customers paying higher fixed charges).

(Chambouleyron, 2003) combines the analysis of optimal water pricing and metering. Consumers are heterogeneous due to the variation in the numbers of household members. Four revenue collecting regimes are compared:
- Rateable Value System (no metering is installed);
- Universal Metering;
- Optimal Metering (the socially efficient number of meters is determined in a centralized fashion; the number of meters installed is the solution to a social planner's problem maximizing welfare and not the water company's profits);
- Decentralized Metering (the optimal number of meters is determined in a decentralized way by the company, which seeks to maximize profit, and in this case it coincides with the socially efficient level).

Universal metering is only advisable if metering costs are compensated by the gain in welfare from the difference between water company's cost savings and consumer surplus losses (resulting from the decrease in consumption by the consumers that were not metered under Optimal Metering but are so under Universal Metering). When the previous condition is not fulfilled the two regimes proposed by the author, Optimal Metering and Decentralized Metering, are able to determine the socially efficient number of meters (respectively in a centralized or decentralized but regulated way)

3.7 Efficiency of block tariffs

As mentioned above, (Gysi and Loucks, 1971) point out the advantages of an increasing block rate schedule combined with a summer price differential.

(Elnaboulsi, 2001) develops a model of optimal nonlinear pricing of water and wastewater services. He considers the issues of temporal variation, capacity constraints, scarcity and consumer heterogeneity. The author concludes that the optimal water tariff design is a two-part tariff (to recover operating/variable and fixed costs). If consumers are homogeneous a single two-part tariff should be implemented. In the presence of heterogeneous consumers a menu of two-part tariffs (with trade-offs between the fixed charge and the volumetric charge) must be implemented. Additional charges should be included in the unit price to reflect the scarcity value of water (in case there is a water shortage) or capacity constraints in any of the water supply and wastewater disposal facilities and transport systems. The utility should offer the consumers quantity discounts, resulting in a decreasing marginal price (not considering the additional charges).

Consumer heterogeneity is an issue yet to be fully investigated in the water pricing literature. It is usually regarded by more general pricing literature as a reason to apply nonlinear pricing schedules (Wilson, 1997).

4. MAJOR RESULTS FROM THE MODELLING OF WATER PRICING

The most consensual result from the water pricing literature is that efficiency requires marginal cost pricing. While this may be common sense for anyone with a minimum microeconomics background, it has stirred up a lot of articles demonstrating the advantages of marginal cost pricing in relation to the widely used average cost pricing practices of many water utilities. There is, however some divergence on whether we should consider short-run or long-run marginal cost pricing. As we have seen, even in dynamic contexts some authors have defended multistage short-run marginal cost pricing.

Although not many articles present a seasonal analysis of prices, it does not seem to be problematic to recognize that, if marginal cost has significant seasonal variations, intra-annual price changes to reflect that variation would enhance efficiency. Assuming continuously changing prices to be unfeasible, the optimal frequency of the price changes would have to be studied. Some authors do try to analyze optimal discrete approximations of price changes to continuously time-varying marginal costs.

A similar problem is that of reflecting on each customer's water bill the specificity of the costs it imposes on the water utility. While the efficiency of doing so is not questioned, the information requirements may be considerable obstacles to this refinement of marginal cost pricing.

It is also consensual that marginal cost tends to rise as the water supply system approaches its capacity limit. If a marginal cost pricing mechanism is in place, the actual water bought by customers may signal the value they attribute to further capacity expansions by revealing their willingness to pay for additional units of water.

The inclusion of the opportunity cost of water in the price when facing capacity constraints has been the subject of many studies, which besides deriving the optimal prices for water also obtain the optimal timing for the expansion of the water supply system. Pure scarcity of the resource has become a concern only in more recent studies, reflecting the shift from the engineering perspective of increasing supply to satisfy demand to the economic perspective of also managing demand through price to efficiently allocate the existing quantity of water supply.

It is also accepted that pure marginal cost pricing may not be feasible or even desirable because of fairness, financial, political or legal reasons. Those concerned with fairness worry that marginal cost pricing could impose an undue burden on the poorest. In situations where the marginal cost falls below average cost, the revenue generated by marginal cost pricing may not be enough to recover the costs leading to financial losses by the water company. On the other hand, if marginal costs rise above average costs, excessive profits made through monopoly supply of what is perceived to be an essencial good may not be acceptable to the public opinion or by legal standards. This raises the question of aiming at efficiency while respecting a revenue requirement. The most common ways of combining these two objectives are through the use of two-part tariffs, adjusting the fixed charge to meet the revenue requirement, or through second-best pricing, collecting the necessary extra revenue where it can be done more efficiently, that is to say, from customers with less elastic demands. These constrained versions of marginal cost pricing would still be preferable to other pricing schemes.

Only a few studies have focused on the question of whether it is optimal to meter every customer, but they are unanimous in saying that, at least, there are conditions in which leaving some connections unmetered may be efficient.

5. SUMMARY

This paper reviewed the articles which present models to determine the water pricing scheme to be adopted and the water prices to be charged. After briefly pointing out some results on existing pricing schemes, the main questions addressed by the water pricing models were systematized and the major results from these studies were presented. Marginal cost pricing is consensually recognized as the most efficient way to price water, but its implementation depends on the characteristics of water supply and demand. Second-best pricing aims at efficiency while constrained by revenue requirements. However, it is not determined if the best way to do it is through two-part tariffs or some other pricing mechanism. The role of block rate pricing, increasingly more frequent in actual pricing practices, is yet to be fully investigated. Some hints for further research are to investigate whether block rates can be derived from efficiency arguments and to study the best way to reflect scarcity costs and temporal variability in water tariffs.

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