MARGINAL OPPORTUNITY COST VS. AVERAGE COST PRICING OF WATER SERVICE: TIMING ISSUES FOR PRICING REFORM

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Abstract

Average cost (AC) and marginal opportunity cost (MOC) pricing rules are compared for public water service in Southwest Florida. A thirty year simulation shows that AC prices are less than MOC prices and the difference between AC and MOC prices is greatest around capacity expansions. These results indicate that the magnitude of the welfare gains available from pricing reform are dependent on the time at which the MOC pricing rule is initiated. In general, the earlier the pricing rule switch is initiated the greater the present value of resource conservation savings less consumer surplus losses associated with higher MOC prices.

Key Words: water service, pricing reform, marginal opportunity cost, average cost, welfare, water supply, externalities

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Introduction

Economic theory is clear on the pricing prescriptions for efficient resource use. For public utilities, this is due primarily to the theoretical and empirical developments in the energy and telecommunications industries, where much of the theory has also appeared in practice (Berg and Tshirhart). The theory of efficient utility pricing has yet to be applied with any consistency in the water service industry. This can be attributed, in part, to the unique features of water service that are not amenable to the theory-based policies developed in other utility industries (Hanemann). Mann, however, suggests three, more compelling reasons why theory has not played a more important role in water service costing and pricing matters:

1. Historically, water service has been provided at lessor cost than other public utility services and has constituted a relatively small proportion of consumer expenditures;
2. The engineering emphasis common in traditional water supply decision making; and
3. The abundance in the past of inexpensive and easily accessible water supplies (p. 163).

The first two factors are ultimately driven by the third, so that the continued presence of easily developed water supplies will probably not change the potency of economic theory in water service pricing practices. On the other hand, in areas where the inexpensive supplies are relatively scarce and the long run costs of capacity expansion are rising, economic theory will have more practical appeal. In these more critical situations, the relative benefits of moving to more efficient pricing practices need to be evaluated in the context of other resource management strategies.

Water Service Pricing Theory and Practice: an Overview

Water service in the United States has traditionally been priced at average or 'embedded' cost (Beecher, Mann and Landers; LaFrancois; Mann). Average cost pricing has no basis in economic efficiency (Baumol, Koehn, and Willig; Hall and Hanemann) and will lead to a wasteful use of resources where the marginal opportunity cost (MOC) of water service is rising (Hirshleifer, DeHaven, and Milliman). It is not clear, though, that water service pricing rules in practice, even those with conservation goals, bear any relation to the marginal opportunity costs of service (Hanke 1978). Subsequently, existing pricing rules, based on average costs, may produce prices that diverge significantly from marginal opportunity costs.

According to Mann, "(t)he neglect of pricing and costing matters has produced the general underpricing of urban water service in the United States" (p. 164). Others have expressed similar concerns, implying that, in practice, water service prices are less than marginal opportunity costs (Mann and LaFrancois; Mercer and Morgan; Moncur and Pollock 1988, 1995). Despite these claims of underpricing, there have been few attempts, if any, to assess the welfare implications of applied pricing reform that would encourage efficient *long-run* resource use. Previous pricing reform welfare analyses have focused on the move to efficient short-run pricing (Kim; Renzetti), peak load pricing (Feldman, Breese, and Obeiter; Hanke 1982), and optimal price solutions to the pricing-investment problem (Dandy, McBean, and Hutchinson 1984, 1985; Riordan 1971a,b; Russell and Shin 1996a,b; Swallow and Marin). This paper examines the implications of a switch from average cost to marginal opportunity cost pricing for water service in the context of Florida's water management system. In particular, it is shown that the timing of pricing reform can affect the magnitude of potential welfare improvements available.

Pricing Rules

average cost pricing

The traditional strategy in water service pricing is to set rates to ensure that the revenue generated from water sales is sufficient to cover total system costs (AWWA). Because this strategy ensures that total revenues equal total costs, average revenue or price will equal average cost. To see this, define the total annual revenue requirements (net of directly attributable system costs) for a water utility serving a single customer class with uniform demand (non-peaking)[1] as $R(q)_t$

$$R(q)_t = [q_{t-1}(g) \cdot c_t] + D_t \qquad \textbf{(1)}$$

where q_{t-1} is the previous year's aggregate water use, g is a growth rate, and c_t is the anticipated marginal (average) operating cost per unit. D_t is the annual debt service given by

$$D_t = \sum_{t=1}^{t} I_t(r) \qquad \textbf{(2)}$$

where I_t is the investment in capacity in year t and r is the capital recovery factor. The average cost price is simply the annual revenue requirements divided by the annual total quantity of water use or

$$P_t^{AC} = \frac{R(q)_t}{q_t} \tag{3}$$

subject to a break-even constraint

$$P_t^{AC} \cdot q_t = (c_t \cdot q_t) + D_t \tag{4}$$

The break-even constraint is added here to reflect the goal of self-sufficiency and fiscal responsibility expected of publicly owned utility services and the ideal of setting rates to recover strictly the costs of service (AWWA; Freedman). In practice, however, some municipalities may view their utility operations as a "money-maker" (Goldstein), whereas others are inclined to provide subsidies to keep rates low (Hite and Ulbrich).

The general average cost pricing rule in (3) presents the allocation of shared costs on the basis of (relative) output. This is an oversimplification in that it assumes all costs are collected in the variable price. In practice, many cost/revenue service functions (e.g. customer costs, hook-up costs) are collected as various fees and not recovered in the unit charge (Mckay et al.). However, because (3) captures the spirit of the allocation process, it will be used as a point of comparison with the marginal opportunity cost pricing rule discussed below.

Marginal opportunity cost pricing

The optimal pricing-investment strategy for water system expansion requires simultaneous selection of prices and the timing of capacity increments. In this case, according to Riordan (1971a), "the particular value of marginal cost relevant for expansion cannot be determined prior to finding the optimal solution to the problem; it is equal to an internal shadow price that is a product of the analysis" (p. 248). The solution calls for a series of price fluctuations to signal coming capacity increments and ration existing capacity (Riordan 1971b). However, the large variations (up and down) in the price level that can occur over time, especially where relatively large capacity elements are considered, may be politically unacceptable. Research has shown that it may be possible to either constrain (Dandy, McBean, and Hutchinson 1984, 1985) or "smooth" (Swallow and Marin) the price paths without significant welfare losses from the optimal case.

Even if the large price fluctuations could be constrained or smoothed to politically acceptable fluctuations, it would be difficult to effect the efficient investment-pricing rule in practice for at least two reasons: (1) water service is priced by water agencies and regulators and not by the market and (2) water use behavior takes time to fully respond to price changes. There are no fully competitive markets for retail water service that can automatically adjust prices to ration scarce system capacity and signal capacity expansion.[2] Furthermore, significant reductions in water use take time and are often permanent or 'hard' and unlikely to respond (back and forth) neatly to the price fluctuations in the optimal investment-pricing model (Hall). Rate-makers could, of course, attempt to set market-clearing prices given perfect information about the water demand function(s) of their customer base. Without this information, though, efficiency minded rate-makers can only approximate market prices for water service. The formulation of marginal cost is critical in this respect: Prices that encourage truly efficient water resource use are set to approximate as nearly as possible the marginal opportunity costs of water service. In addition, it is important for system planners to account for the peculiar ways in which demand may respond (e.g. hardening) to cost/price changes.

An effective approximation of the efficient investment-pricing rule will emulate the rationing-signaling effect of the market and account for the full range of marginal opportunity costs associated with a unit of water use. The marginal opportunity cost framework for resource valuation has been adapted for both water service (Warford) and electricity supply pricing (Munsinghe and Schramm) and appears generally as

$$MOC_t = c_t + C_t + E_t + u_t \qquad \textbf{(5)}$$

where c_t is marginal operating cost, C_t is marginal capital cost, E_t is marginal external or environmental cost, and u_t is marginal user cost.

Marginal capital cost (MCC) is not well defined for utility services due to capital indivisibilities (Crew and Roberts; Williamson) and must be approximated. Saunders, Warford, and Mann presented an early review of approximations to MCC in the presence of indivisibilities. Russell and Shin (1996a,b) capture the important features of their findings and add considerably to the understanding of the MCC formulae: textbook marginal cost (TMC), Turvey marginal cost (TVMC), and average marginal cost (AMC). These three formulae all focus on future water supply and cost circumstances, however, they differ in the way in which they make future capital costs marginal to current consumption decisions. Russell and Shin (1996b) find that TMC, TVMC, and AMC perform reasonably well (i.e. they produce favorable net benefits over the existing pricing rule) when the capacity increments are arranged optimally over the planning horizon via a dynamic programing application. Performance is mixed, though, when capacity increments are not optimally configured. The welfare performance of AMC is not significantly affected by the optimallity of capacity timing, whereas the welfare improvements available from TVMC are dramatically reduced. This makes intuitive sense because the TVMC method is formulated in the time dimension where efficiency distortions can easily occur from capacity increments out of synch with demand or projects being developed out of least-cost order.[3] In addition, AMC yielded greater present value net benefits than TVMC and TMC (and the existing pricing rule) in both situations and produced less price variation over time. In light of these results, AMC is the choice formulation of MCC for the present research.

The AMC formulation of MCC fashions a compromise between the efficient price signal and political constraints on price fluctuations by averaging the present value sum of unit investment costs over the planning horizon. The averaging acts to "smooth out lumps in expenditure streams while at the same time reflecting the general level and trend of future costs which will have to be incurred as water consumption increases" (Saunders, Warford, and Mann p. 27). Russell and Shin (1996a) present AMC as

$$MCC_t = AMC_t = \frac{1}{(1+i)^{k-t}} \frac{\sum_{\hat{t}=k}^{T} (r) \frac{I_{t+\hat{t}}}{(1+i)^{\hat{t}-k}}}{\sum_{\hat{t}=k}^{T} \frac{\Delta Q_{t+\hat{t}}}{(1+i)^{\hat{t}-k}}} \tag{6}$$

where I is the capital cost of capacity increment ΔQ, i is the discount rate, and r is the capital recovery factor. Subscript k denotes the very next capacity added year after t and subscripts 1 through T denote every other year over the planning horizon.[4]

Marginal external cost (MEC) is meant to represent any current cost(s) caused by the use of a unit of water that is not reflected in the marginal (private) operating cost of water service.

These external costs are generally in the form of (current) forgone valued use opportunities for a resource unit when it is devoted to water service. For example, water withdrawn from a interrelated ground-surface water system is no longer available to maintain wetland ecology. To the extent that wetlands are valuable, the value of any wetland loss due to groundwater withdrawal is an opportunity cost of groundwater use. In this case, it is efficient to withdrawal groundwater to the point where the marginal value of wetlands forgone is equal to the marginal benefits gained when the groundwater is employed in another valued use, like for public water supply. Figure 1 (adapted from Thomas and Martin) demonstrates how the equalization of marginal values could stabilize groundwater withdrawal levels and wetland loss in the presence of growing demand for public water supply.

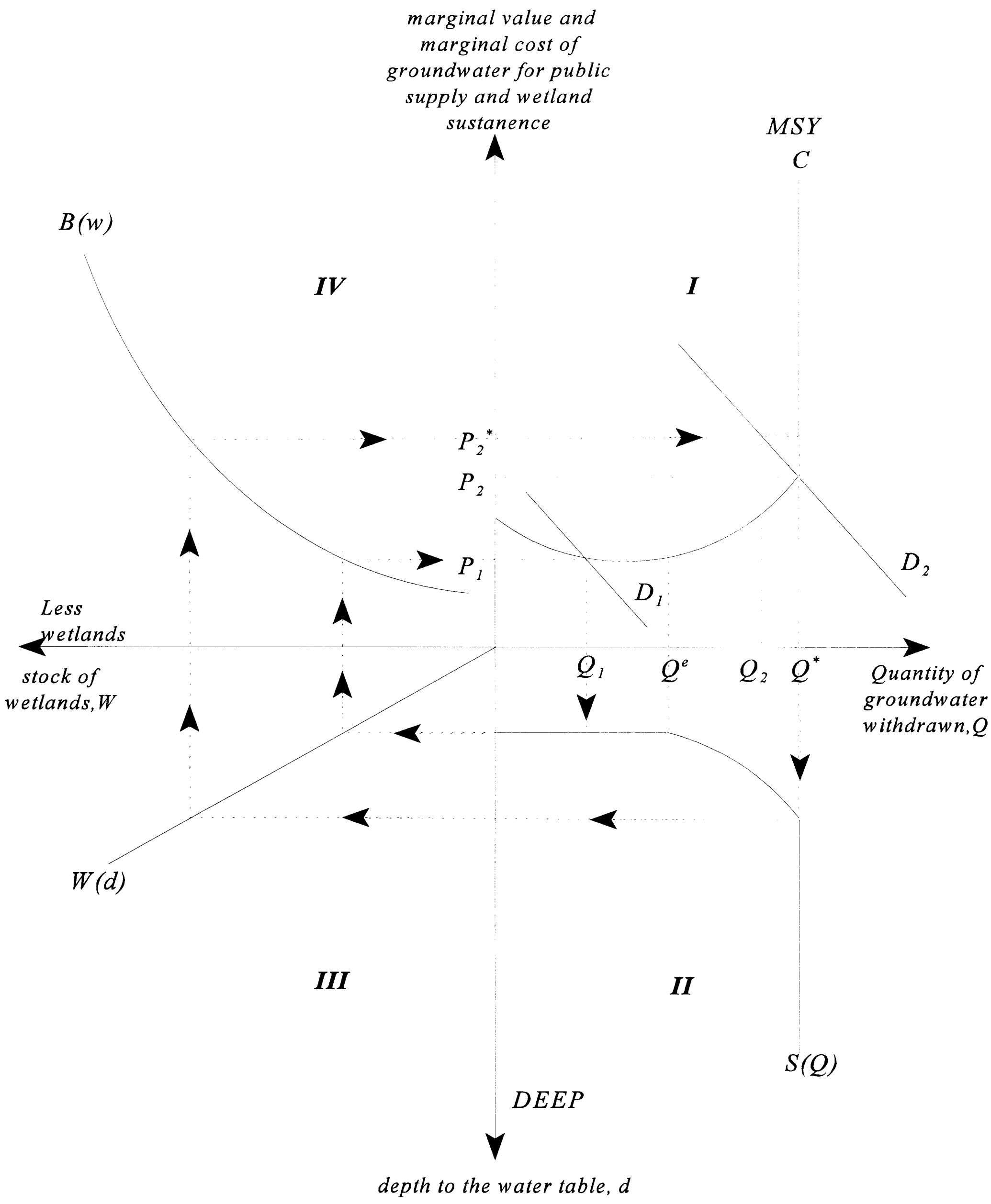
Groundwater system development is shown as a function of the water table depth d associated with a specific level of ground water withdrawal Q. Groundwater withdrawal equals recharge at the maximum sustainable yield (MSY) at quantity Q^*. At MSY wetlands near concentrated wellfield pumping are eliminated since they represent a major source of evaporation losses in the interrelated ground-surface water system (Serrano and Serrano; SWFWMD). The relationships among the graph quadrants are as follows:

I. The quantity of groundwater withdrawn is determined at the intersection of the demand curve D and the private marginal operating cost (c_t) curve C in quadrant I. Note that C is the short-run marginal cost of water production and is vertical at the MSY of the aquifer due to regulations on groundwater withdrawal and/or water system capacity limits;

II. The quantity of water withdrawn determines the depth to the groundwater table with the stock function S(Q) in quadrant II;

III. The depth to the water table specifies the amount of groundwater *not available* for wetland sustenance in quadrant III. The existing stock of wetlands (measured on the negative half of the horizontal axis where 0 is the maximum stock) is a function W(D) of the depth to the water table; and

Figure 1. Groundwater System Equilibrium in the Presence of Environmental Externalities (adapted from Thomas and Martin)



IV. The benefits of (demand for) wetlands is a function B(W) of the available wetland stock in quadrant IV.

At withdrawal levels between 0 to Q^e, marginal external costs are negligible and marginal private costs equal marginal social costs. For instance, at D_1, the equilibrium price and quantity are P_1 and Q_1, respectively. Following Q_1 down to the stock function in quadrant II, across to the wetland loss function in quadrant III, up to the wetland benefit function in quadrant IV, and finally across to the price axis we see that the value of wetlands stock (loss) or marginal external cost is roughly equal to the marginal private cost price P_1. However, withdrawal of the MSY quantity Q^* to meet demand D_2 at the marginal private cost price, P_2, leads to a drop in the water table, a loss of (water available for) wetlands, and an increase in marginal external costs to P_2^* (including the MPC). At this point, if the price remains equal to the marginal private cost, P_2, the system is out of equilibrium and a social efficiency loss occurs equal to the shaded triangle: water users are over consuming because the value of Q_2 - Q^* to them is less than the social cost (marginal private cost + lost wetland benefits). The system can be brought back into equilibrium two ways. The first would be to internalize the marginal external costs in the price for water service by charging P_2^* for a unit of water so that a quantity, say Q_2, between Q^e and Q^* is demanded. Revenues collected over total private costs could be used to somehow compensate for the lost wetland benefits or to mitigate the wetland damage. The former would be the Pareto-superior option, but the lack of knowledge about the wetland damage (benefits) function and the likely confusion surrounding payment of compensation make the option of mitigation more appealing in practice. However, it may be that the uncertainty associated with mitigation success is such that regulatory agencies charged with protecting wetland systems may set groundwater withdrawal limits or quotas to prevent rather than allow mitigation of wetland damage (Baumol and Oates 1989, Chapter 5). For example, pumping restrictions, like those considered recently to protect Florida's groundwater systems, would appear in Figure 1 as a leftward movement of Q^* which would now represent the maximum *allowable* system capacity. Ideally, the withdrawal limitation would be set where the marginal value of groundwater withdrawal for public supply use given by D_2 equals the marginal value of groundwater to maintain wetland stocks (possibly at Q_2). With stable demand this leftward movement of Q^* prohibits withdrawal quantities that cause wetland losses, thereby reducing or eliminating MECs. Some combination of withdrawal limitations and wetland mitigation requirements could also achieve (quasi) equilibrium *if* the mitigation costs are included in the marginal charge for water service. The Florida case study considered below is a hybrid approach on this order.

Marginal user cost. Marginal user cost (MUC) is an opportunity cost of water service in terms of valued future use opportunities forgone for a unit of water of present quality at present cost. This opportunity cost becomes significant in water service where it is anticipated that potable water production is to be more costly ($c_t + E_t$) in real terms at some point in the future. Here we are concerned with the ability of the existing water system to meet the demands of future customers. On equity grounds it can be argued that future customers are entitled to potable water service at a real (social) cost no greater that incurred by present customers, ceteris paribus (Hanke and Wenders). Subsequently, where it is expected that in the foreseeable future an additional unit of potable water will cost more to produce and deliver than it does presently, the current costs/prices for water service should reflect the relative scarcity of the resource (Martin et al.; Moncur and Pollock 1988).

Exhaustible resource theory presents scarcity rent or user cost as the difference between the market price and the marginal extraction cost of a resource (Heal). This approach is not strictly applicable for water service because, as discussed earlier, retail water service prices are "set" and not market determined. With this problem in mind Moncur and Pollock (1988) develop a simple expression of user costs for water service:

$$MUC_t = \frac{c_T^* - c_t^*}{e^{i(T-t)}} \tag{7}$$

where i is the (social) discount rate, and c^*_t and c^*_T are, respectively, the social marginal operating costs (including external costs, i.e. $c_t + E_t$) of water service today (period t) and at the end of the planning horizon (period T) when the replacement or backstop technology is brought on line. Note that this user cost adaption for water service follows in the spirit of the formulation commonly used in applied analyses of energy resource pricing and investment (e.g. Schramm or Hohmeyer). Marginal user cost in (7) is the present value magnitude of the difference between the marginal (social) cost of water service in period t and at the end of the planning horizon T with the backstop technology. This is essentially a compromise between the lower bound on water resource opportunity cost given by the current marginal social cost c^*_t and the upper bound on opportunity cost at the replacement marginal social cost c^*_T. The present value connotation supposes that the MUC and, thus the efficient price of water service (because $P = c^*_t + u_t$), will move over time in accordance with the interest rate, depending on the path of c^*_t. Symbolically, with an efficiency price P_t given as

$$p_t = c_t + \frac{c_T^* - c_t^*}{e^{i(T-t)}} \qquad \textbf{(8)}$$

and assuming c^*_t constant, the rate of change in the efficiency price for water service is

$$\dot{p} = \frac{p_{t+1} - p_t}{p_t} = i \qquad \textbf{(9)}$$

This the familiar Hotelling rule that the market price of an (exhaustible) resource must grow at a rate equal to the rate of interest. In effect, then, the MUC formulation in (7) assumes market characteristics on the behavior of water system costs and prices over time. Also, note that user costs are sensitive to (expectations about) the rate of technological change and the social cost of the backstop: an increase (decrease) in the marginal social cost c^*_T of water from the backstop technology will increase (decrease) the user cost of consumption from existing water supplies.

The user cost formulation (7) estimates a marginal opportunity *cost* of present water resource use and is not a measure of the (scarcity) *value* of water resources: value or scarcity value can only be expressed by what the water demander is willing to sacrifice to either use or conserve scarce water resources. Scarcity values, where present, represent an upper bounds on the amount of user cost or scarcity rent that can be generated through water service fees (Moncur and Pollock 1989). Subsequently, the collection scarcity rents or user costs in water service may be less important where scarcity values for water resources are effected through other mechanisms, say via institutional action (Lynne).

The expanded definition of the marginal opportunity cost of water service given in (5) is

$$MOC_t = c_t^* + \left[\frac{1}{(1+i)^{k-t}} \cdot \frac{\sum_{\hat{t}=k}^{T} (r) \frac{I_{t+\hat{t}}}{(1+i)^{\hat{t}-k}}}{\sum_{\hat{t}=k}^{T} \frac{\Delta Q_{t+\hat{t}}}{(1+i)^{\hat{t}-k}}} \right] + \left[\frac{c_T^* - c_t^*}{e^{i(T-t)}} \right] \quad \textbf{(10)}$$

where the notation is as presented above (note that c* includes marginal external costs).

Average Cost vs. Marginal Opportunity Cost

Consider the differences between the AC pricing rule in (3) and the MOC pricing rule in (10):

Difference 1: The MOC rule explicitly considers external costs as a part of short run marginal costs c, whereas the AC rule may not.

Difference 2: In the MOC rule, (unattributable) capacity expansion costs are collected in the marginal price prior to the capacity start-up (second term). The AC rule collects (unattributable) capacity expansion costs as an average (in SC) after the capacity is in place (second term).

Difference 3: The MOC rule recognizes future opportunity costs with a user cost component (third term), the AC rule does not.

The first difference will only be significant to the extent that average cost accounting methods in practice do not consider the external costs of water service. In many areas, regulations require water suppliers to mitigate external costs, such as those associated with environmental degradation. Where this occurs external costs become (approximately) internalized in accounting practices and, therefore, appear in AC prices.[5] Whether these mitigation costs are collected at the margin in c or as an average as part of shared costs is not likely to change the end-use average price. Where the mitigation costs are collected in fixed charges, though, potential signaling benefits would be dampened or eliminated because marginal consumption decisions are not fully informed about the marginal external costs of water use. Regulatory action could also function to prevent external costs by imposing restrictions on water use (withdrawal) from a particular source to avoid the damaging levels of use. In such cases, external costs are reduced or eliminated and will not contribute to the divergence between AC and MOC prices.

The second difference between the AC and MOC rules is a matter of timing, that is, both rules account for all capacity expansion costs, it is just a matter of when. The MOC rule charges a MCC for capacity costs ahead of time in order to preserve signaling benefits and consumer choice. The MCC component of MOC is, in theory, highest just before a capacity expansion, lowest after a capacity element is installed (sunk) and will be zero when no future capacity investment is planned. On the other hand, the AC rule does not charge for capacity expansion until the investment can be considered "used and useful" and/or debt service payments begin to factor into the revenue requirements.[6] Therefore, the AC rule exhibits the lowest prices (assuming economies of scale) just before capacity expansion and the highest prices right after capacity is installed. This timing schedule works completely counter to economic efficiency as water use is encouraged with relatively low prices when capacity is scarce and discouraged with relatively high prices when surplus capacity exists.

The third difference between the AC and MOC pricing rule reflects the notion that marginal user costs are typically not included in traditional AC water service prices (Moncur and

Pollock 1988). Higher user costs will, of course, mean higher MOC prices and a greater divergence between AC and MOC prices. From (6), the magnitude of marginal user cost in any period t will depend on the spread between current system marginal (social) costs and future system marginal (social) costs with the replacement (backstop) technology $(c^*_T - c^*_t)$, ceteris paribus.

With the above said, we can specify four conditions regarding the difference between AC and MOC prices:

1. We cannot say *a priori* what effect the magnitude of external costs will have on the difference between AC and MOC prices. To the extent that water suppliers are required to mitigate external costs, these costs will be included in system accounts and in the AC price for water service. In these cases, the difference between MOC and AC prices will depend on whether mitigation costs are collected with fixed charges or at the margin.
2. The divergence between AC and MOC prices will be most significant just after and, more importantly, just before a capacity expansion. Before (after) capacity expansion MOC>AC (MOC<AC).
3. For any period, the divergence between AC and MOC prices depends on the degree to which (real) historic and future capacity expansion costs differ. Relatively higher (lower) future costs suggest MOC>AC (MOC<AC).
4. For any period, the divergence between AC and MOC prices depends on the magnitude of the difference between current system marginal (social) cost and future system marginal (social) cost with the replacement (backstop) technology. We cannot say *a priori* whether high (low) user costs will have MOC>AC (MOC<AC).

The potential welfare improvements available from MOC pricing in an area will depend (unambiguously) on conditions two and three. Assuming that condition three is significant (i.e. new supply costs are greater than historic capacity costs) the consequences of maintaining the AC rule will be most noticeable before and after capacity expansions.

Simulation

The analysis considers the definition of average cost (AC) pricing presented in equations (1) through (4) and three definitions of marginal opportunity cost (MOC) based on equation (10). The MOC price formulas range from a basic formulation (MOC1) that includes only marginal operating and capital costs to a "fully-loaded" formulation that includes external cost and user cost components. Symbolically,

$$MOC1 = c_t + C_t \tag{11}$$

$$MOC2 = c_t + C_t + E_t \tag{12}$$

$$MOC3 = c_t + C_t + E_t + u_t \tag{13}$$

For the AC and MOC1 formulations, any external costs of water service that have been internalized (e.g. as environmental mitigation costs) are assumed to be collected through fixed annual or monthly fees that in total equal

$$F_t^E = E_t \cdot q_t \tag{14}$$

where the notation is as described above. Depreciation and inflation are assumed to be zero (on net) for all pricing simulations over the planning horizon.

Study area and background

The AC and MOC formulae set forth in the previous section are simulated using data from the West Coast Regional Water Supply Authority (now known as Tampa Bay Water, hereafter WCRWSA) in Southwest Florida. The WCRWSA *wholesales* raw and potable water at cost to six member governments who, in turn, provide retail water service to 1.8 million residents in the area surrounding Tampa Bay, Florida. In 1995, the WCRWSA averaged 127.6 million gallons per day (mgd) of water production from eleven wellfields throughout the region. This supply in combination with water production from member operated facilities (93.7 mgd) provided over 220 mgd in 1995 to meet water demands in the region. The total existing capacity in the region is 311.7 mgd and regional water use is anticipated to grow to 304 mgd by 2015 and 344 mgd by 2030 (Law Environmental in association with Havens and Emerson). Subsequently, new capacity will be "needed" before 2015. The supply deficit may be more or less significant in certain areas depending on the degree of interconnection and the location of new capacity additions.

The WCRWSA is responsible for the development of new water regional supply sources on behalf of its member governments (Regional Water System Contract). Any new supply sources will add capacity to the so-called Regional System production that is shared in "common" by the member governments. Since member governments cannot develop their own new water supply sources the cost of new water supplies to the regional system defines the long run marginal cost of potable water in the region. During 1994, the WCRWSA developed a Water Resource Development Plan (RDP) to evaluate the future water supply options in the region. The RDP concludes with a suggested Master Water Plan that specifies a strategy for new capacity additions through the year 2030, including rather detailed estimates of costs associated with various capacity increments that were used in the present analysis

We simulate wholesale MOC and AC prices for water from the Regional System using a *static* (i.e. "non-optimized") capacity expansion plan (see Table 1).[7] However, as noted previously, recent research suggests that the net benefits of pricing with the average marginal cost formulation of MCC used in the present study are relatively insensitive to the optimality of the capacity expansion plan (Russell and Shin 1996b). The estimated wholesale water prices are then converted to (uniform) retail prices to evaluate the net benefits of efficient pricing in the Tampa Bay region.[8]

Backstop technology

A backstop technology must be identified in order to calculate the user cost component of marginal opportunity cost. The backstop technology considered in this analysis is a 32 mgd seawater desalination plant (see Table 1). Desalination is not the only potential backstop water supply in the study area. Long distance interbasin water transfers have also been considered as a backstop source. However, desalination is being pursued before such transfers under the guise of a "local sources first" policy instituted by the SWFWMD and Florida water law. This policy stipulates that Gulf water desalination is a local source and must be examined before long-distance inter-basin or inter-district transfers are considered. Given that the marginal operating cost of desalination ($3.62) is more than twice that estimated for a comparable supply via inter-regional transfer ($1.56 for a transfer from Lake Rouseau to the north), the decision to pursue desalination before transfers is *not based purely on least engineering costs*.[9] Therefore, policy makers are implicitly recognizing other socioeconomic and political opportunity costs associated with the long-distance transfer that are not considered in the engineering cost estimates.

There remains the question of technological improvements that may affect (lower) the cost of water from the backstop. A report on desalination prepared for the California Urban Water Agencies (Boyle Engineering 1991) includes an entire section on the "potential for technology improvements" in which it is concluded (p. 43): "Although there will undoubtedly be some improvements (in desalination technology), the only 'breakthrough' that is likely to result in major cost reductions would be the development of a cheaper power source." This applies to both membrane and distillation desalination processes. Consequently, predictions about future cost savings in the desalination process appear to require speculations about the cost of electricity and energy in general. Nonesuch speculations are made for this analysis, although, we could assume that any cost savings from technological improvements are offset by increases in energy costs. In any case, it is assumed that the marginal operating and environmental costs (c + E) of water from the WCRWSA Regional System reach a maximum by 2030 and thereafter remain constant (or decline) into the indefinite future. In other words, specification of seawater desalination as the backstop technology is legitimate. If it turns out that costs actually continue to rise, then the marginal user cost and associated marginal opportunity costs calculated here will be understated. Subsequently, our estimates can be considered a lower bounds on potential user cost for water service in the study area.

Table 1. WCRWSA Regional System Capacity Expansion Plan

capacity element	startup year	Capacity (kgal/day)	Capital Costs (000)	Annual Costs (000)			$/kgal
				O&M	Environ. Mitigation	Well Mitigation	
Cypress Bridge Permit Increase	1997	4,000	$1,400	$274	$50	$50	$0.26
Keller Connector Transmission Main	1998	0	$3,760	$32	$0	$0	$0.02
Cypress Creek 84" Transmission Main	1998	0	$22,275	$208	$0	$0	$0.02
Tampa/Hillsborough Interconnect	1998	8,000	$1,700	$30	$0	$0	$0.01
Cosme Transmission Main	1999	0	$15,550	$142	$0	$0	$0.02
North-Central Hillsborough Intertie(d)	1999	0	$28,210	$294	$0	$0	$0.02
Industrial-Agricultral Exchange	1999	12,000	$36,589	$832	$150	$150	$0.26
South-Central Hillsborough Intertie	1999	0	$18,881	$170	$0	$0	$0.02
Tampa Bypass Canal Linear Wellfield	2001	10,000	$17,579	$1,903	$100	$200	$0.60
Brandon Urban Wellfield	2001	12,000	$23,886	$1,078	$100	$200	$0.32
Cone Ranch and Dispersed Wells	2001	12,000	$40,405	$1,407	$100	$200	$0.39
Loop 72 Transmission Phase A	2001	0	$24,500	$150	$0	$0	$0.02
Brackish Water Desalination (a)	2003	4,000	$15,626	$1,268	$0	$0	$0.87
Central Pasco Intertie	2003	0	$10,836	$108	$0	$0	$0.02
Lake Bridge Booster Station	2003	0	$7,930	$43	$0	$0	$0.02
Cypress Creek Booster Station	2003	0	$7,380	$40	$0	$0	$0.02
Hillsborough Bay Resource Exhange	2004	35,000	$109,667	$12,620	$300	$1,500	$1.13
Brackish Water Desalination (c)	2011	12,000	$46,878	$3,804	$0	$0	$0.87
Seawater Desalination (a)	2011	4,000	$21,400	$5,296	$0	$0	$3.63
Seawater Desalination (c)	2024	32,000	$167,471	$42,368	$0	$0	$3.63

Source: Law Environmental in Association with Havens and Emerson (1994) and Bolyle Engineering (1996).

Demand for Water in Southwest Florida

The single family demand model[10] used to compare AC with MOC pricing rules is based on an analysis of water use in Southwest Florida (Brown and Caldwell in association with John Whitcomb) and measures the percentage change in a base single family water use q_b^{sf} due to percentage changes in combined water and sewer prices P:

$$q(P)^{sf} = q_b^{sf} * \left[1 + \beta_1 * (7.05 - P)^{\beta_2} \right] \quad \textbf{(15)}$$

Base water use q_b^{sf} is a function of an intercept, persons per household, net irrigation requirements, irrigation restrictions, lot size, and the existence of an irrigation well or pool.[11] The percentage changes in price are measured with deviations from the maximum sample price of \$7.05/kgal and price responsiveness is given by the parameter estimates β1 and β2. In this way, the model is flexible, allowing price elasticity to vary with price level.[12] Note, however, that elasticity is forced to zero at a price of \$7.05.

The difference D_q between single family daily water demand with average cost prices $D(P_{AC})$ and the demand with marginal opportunity cost prices $D(P_{MOC})$ is given by

$$D_q = D(P_{MOC}) - D(P_{AC}) \quad \textbf{(16)}$$

In terms of the single family demand equation in (18), this difference is

$$\Delta q_{sf,t}\Big|_{P_{AC}}^{P_{MOCi}} = q_B^{sf} * \left(\left[1+\beta_1 * (7.05-P_{MOCi})^{\beta_2}\right] - \left[1+\beta_1 * (7.05-P_{AC})^{\beta_2}\right] \right) \qquad \textbf{(17)}$$

The water use responses to price changes measured in the Southwest Florida demand study reflect long-run adjustments in water use patterns. This is significant for the present analysis in two ways: (1) the full quantity changes in water use with respect to price cannot be expected to appear immediately (less than a year) following a price change, and (2) the price responsive changes in water use behavior will reflect long-run (opportunity) values for water service. The first point suggests that year to year water use changes due to price changes should be taken with caution and may be viewed as over or under estimates of actual responses depending on the direction of the price change. The second point is important because the relevant measure of the long-run (marginal or average) costs for water service should include customer investments in water efficiency (Hall). Changes in water use patterns in the long-run include customer investments in water efficiency and, therefore, are indicative of the cost (value) of conservation to the customer relative to the (opportunity) cost of new capacity development. Prices based on (forward-looking) marginal opportunity costs act to maximize the benefits from this trade-off. The final estimates of per unit single family household and commercial water use are "grossed up" to determine the WCRWSA Regional System water use and net revenues with the different price formulations.[13]

Welfare measures: relative net benefits of pricing rules

Single family households are used to "gauge" the relative net benefits available with a switch from average cost pricing to marginal opportunity cost pricing. That is, net benefits of efficient pricing are figured as resource or opportunity cost gains (losses) less any losses (gains) in annual consumer surplus per an average single family household. The resource costs gained or conserved are denominated in terms of avoided externalities and deferred higher water supply costs. These resource cost savings are a public good and accrue to the community as a whole, whereas the loss in consumer surplus is a private phenomena. Conceptually, individual single family welfare is being traded off for the public welfare good of conserved resource costs. This trade-off involves a choice between the use of groundwater to satisfy water service values and values for environmental integrity or future valued groundwater uses. Accordingly, the conservation that occurs with marginal opportunity cost pricing represents maintained resource integrity for future generations.

Figure 2 illustrates in greater detail the welfare changes we are interested in measuring. Assuming marginal opportunity costs are greater than average costs, $P_{MOC} > P_{AC}$, net welfare at P_{AC} is total surplus minus resource (opportunity) costs or [F+A+B+D+E] - [A+B+C+D+E] = F-C. Similarly, at P_{MOC} net welfare is [F+A+B+D+E] - [A+B+D+E] = F. The net change in welfare from charging P_{MOC} instead of P_{AC} is F - [F-C] = +C. In the switch from average cost to marginal opportunity cost prices household water users *loose* consumer surplus equal to A+B, but the community *gains* in conserved (or compensated) resource (opportunity) costs equal to area A+B+C. Thus, the net resource gains (potential Pareto improvement) from efficient pricing per single family household are equal to the shaded triangle C which is analogous to the shaded area in Figure 2.

Annual single family household net benefits (NB) from a *discrete* switch to MOC pricing in year t are given by

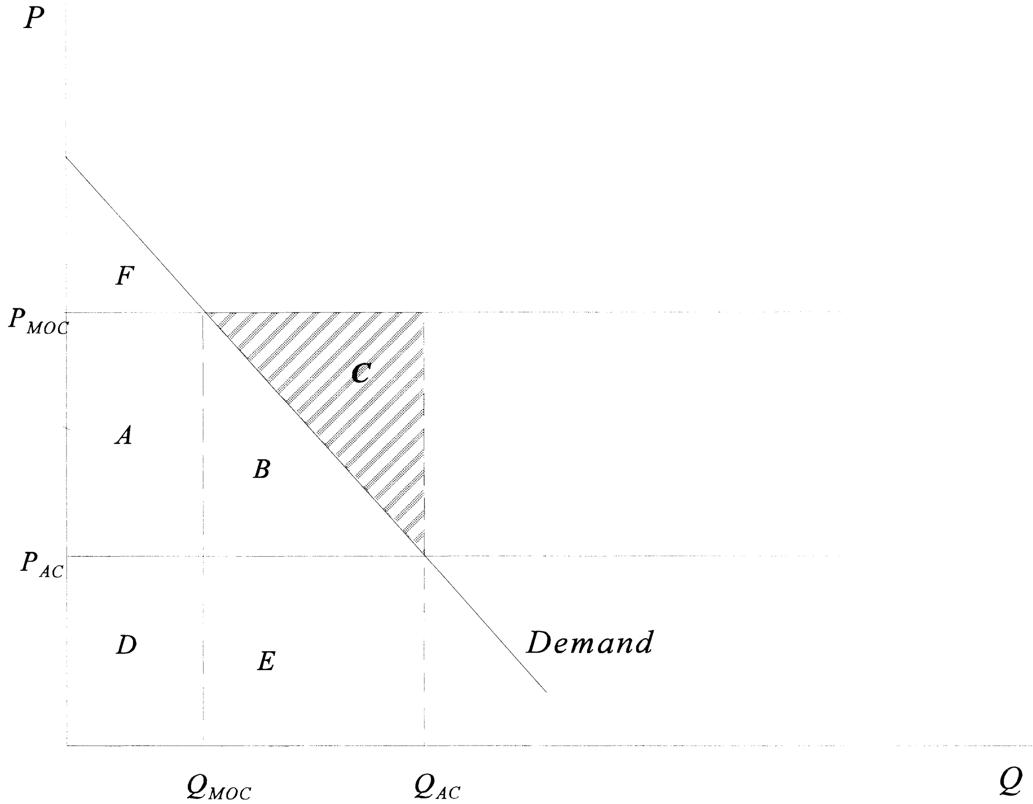
$$NB_t = [(P_{MOCi} - P_{AC}) \cdot q(P_{AC})] - \left[\Delta CS \int_{P_{AC}}^{P_{MOCi}} q(P)dP \right] \tag{18}$$

where the first term on the right measures the resource cost of use level $q(P_{AC})$ (area A+B+C) and the second term measures the area under the demand curve between P_{AC} and P_{MOC} (area A+B). Integrating equation (18) from P_{AC} to P_{MOC} gives the annual change in consumer surplus:

$$NB_t = \Delta CS_t = \int_{P_{AC}}^{P_{MOCi}} Q(p)dp = q_B^{sf} * \left[P - \beta_1 \frac{(7.05-p)^{\beta_2+1}}{\beta_2+1} \right] \Bigg|_{P_{AC}}^{P_{MOCi}} \tag{19}$$

This Marshallian welfare measure of equivalent variation is used because compensation variation cannot be measured due to the lack of an income parameter in the demand model.[14] The discrete

Figure 2. Measurement of the Net Benefits from a Switch to MOC Pricing



measure of net benefits shows the relative net annual benefits from efficient pricing available in any given year over the planning horizon. However, given that pricing policies are rigid in practice and not apt to switch from year to year, a more practical indicator of the benefits of efficient pricing is the present value net benefits of a *permanent* switch to MOC pricing in year t

$$PVNB_{\hat{t}} = \sum_{t=\hat{t}}^{T} NB_{t+\hat{t}} \qquad \textbf{(20)}$$

This formulation of PVNB accounts for the fact that benefits may be lost (or gained) by postponing (accelerating) the time at which the switch to marginal opportunity cost pricing takes place.

Results and Discussion

Price Path Stability

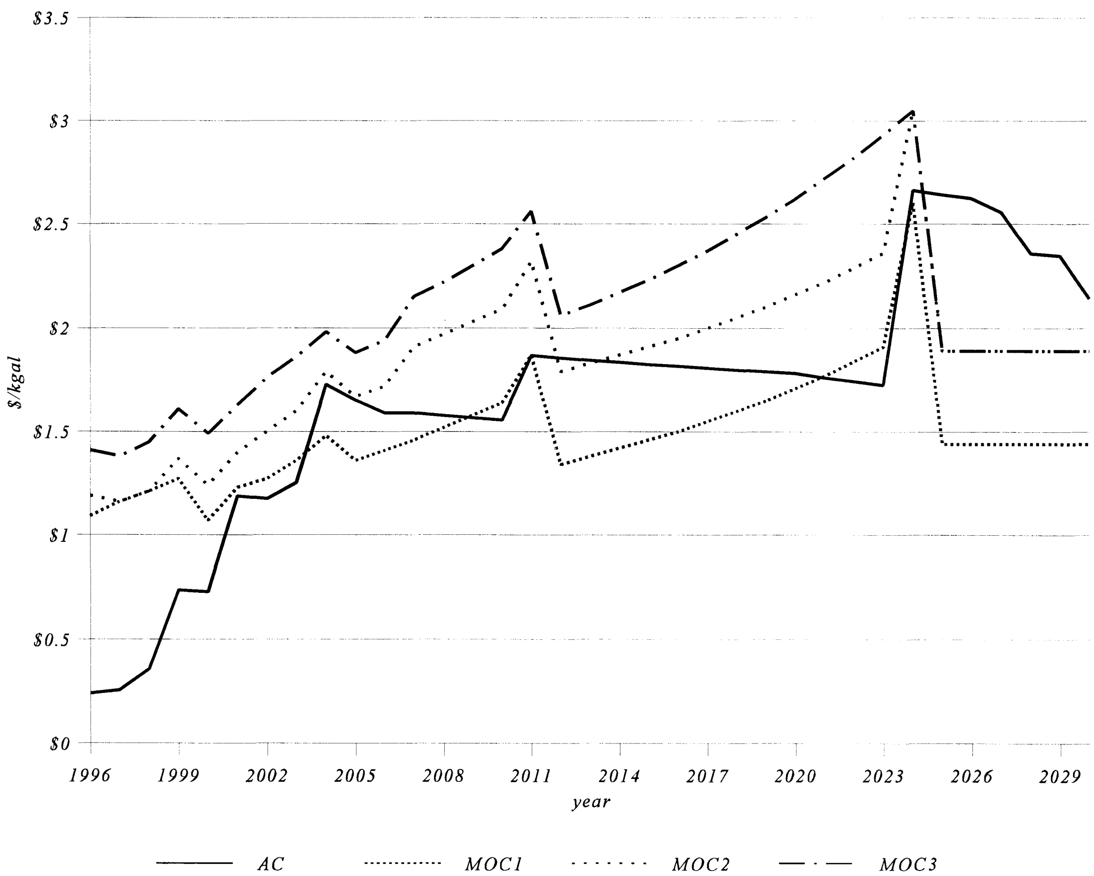
Table 3 presents the coefficients of variation for the AC and MOC price paths. Coefficient of variation ($\sigma_{n-1}/\overline{x}$) is a measure of the variability of the prices about the mean for the planning horizon. It expresses the standard deviation of the price paths as a function of their means. The coefficients in Table 3 show that the MOC price paths are remarkably consistent about the mean, though this does not necessarily indicate that the paths are stable. Russell and Shin found coefficient of variation for the average marginal cost formulation of 24%. Their formulation is comparable with our MOC1, which showed a high coefficient of variation of 6.6% and a low of 6.2%.

Table 4. Coefficients of Variation for the Estimated Price Paths from 1996 to 2030

	Coefficients of Variation (%)			
interest rate	MOC1	MOC2	MOC3	AC
.03	6.2	8.1	6.6	11.8
.07	6.6	7.9	8.9	12.8

Figure 3 presents the predicted AC and MOC price paths over the planning horizon with a .07 interest rate. In the figure we see that the relatively low coefficients of variation for the MOC paths occur because price increases are typically matched with equivalent (or greater) price decreases over the planning horizon. This price variation acts to ration scarce capacity before system expansions and to signal the efficient timing of expansions. In this way, the MOC formulations emulate the efficient pricing-investment path estimated by Riordan (1971b). Note,

Figure 3. Marginal Opportunity Cost and Average Cost Price Paths



however, that in most cases the MOC price paths fluctuate within a reasonable bounds (within roughly \$.50) and it is single year price *decrease*s, not increases, that are most intense. The narrow band of price fluctuation is due to the blending of system costs. That is, price fluctuations would sharpen if the Regional System wholesale MOC prices were considered independent of other area supply source costs. The relatively dramatic price decreases occur after capacity expansion when the preceding capital investment is removed from the price signal because it is no longer marginal (avoidable) to water use decisions. As long as expansion or replacement capacity is anticipated in the future, though, there will still be a marginal capital cost element in the MOC price signal.

The coefficients of variation for AC prices are relatively high due to the large price increases that occur in years when capacity is added (see spikes in Figure 3). The high capital and operating costs of the backstop technology (desalination) cause the AC price to jump dramatically in the year the facility goes on line (around \$1.00). The MOC formulations also spike in this year, but the magnitude of the price jump(s) is dampened due to the forward-looking nature of these prices (<.\$70). In fact, with MOC3 there is no sharp price increase because the user cost component was signaling the backstop capacity expansion long before it occurred. These results suggest that the MOC formulations, especially MOC3, can alleviate rate-shock in the future. Notice, however, that the initial switch to MOC pricing does involve a substantial price increase. Once a MOC pricing rule is adopted, though, the transition to higher cost water supplies is gentler than the AC rule.

Timing

The AC and MOC prices are similar *on average* because the interest rate plays an important role in the allocation of capital costs for both formulations. As long as the same interest rate is used in both rules the mean prices should be relatively similar. In effect, the MOC rule generates "prepayments" based on the present value of future capacity investments that will vary depending on the timing and size of the anticipated capacity increments and the interest rate. These prepayments are greater than AC debt service, initially, but as more capacity becomes "used and useful" over the planning horizon, the annual debt service in AC overtakes the capital component in MOC formulations.

Finding similar mean prices does not tell us much about the divergence between AC and MOC prices at different points on the planning horizon. There is reason to suspect that this divergence is not constant: In the AC pricing rule capital costs are discounted and spread out *after* an investment occurs, whereas the MOC rule discounts *future* capital costs to present value for pricing purposes. It was posited in point 2 in the AC vs. MOC section that this process reversal would show up as significant divergences between the AC and MOC prices just before and after capacity expansions. Capacity expansion points can be identified as spikes in the AC and MOC price paths in Figure 3. The greatest differences between AC and MOC price specifications are noticeable around capacity expansions. What is most striking is the difference between MOC and AC prior to the first capacity expansion and following the final (backstop) increment. The former is evidence of "underpricing" and the latter "overpricing" (assuming the MOC price paths are efficient).

The MOC2 and MOC3 paths are slightly above the MOC1 path over the planning horizon because they include marginal external(mitigation) costs. The corresponding greater relative difference between MOC2 and MOC3 and AC price paths implies that environmental and/or user costs are important. This, again, suggests that at the AC prices water service are "too low" in some years and "two high" others.

In summary, the AC rule produces prices that work counter to economic efficiency. Water use is encouraged with relatively low prices when capacity is scarce and discouraged with relatively high prices when surplus capacity exists (cf around 2011 and 2025 in Figure 3). With the AC rule, there is no price signal regarding the backstop technology or any other capacity increments[15] and water service is underpriced in years prior to the investments. In the years immediately following (lumpy) capacity expansions, AC prices are relatively high because production economies are not yet realized. This is most noticeable after the backstop where AC prices peak and then decline steadily as the system approaches capacity and the average capital cost of the backstop investment is spread out. The backstop capital costs will continue to be allocated in this way for the useful life of the facility (30 years) with the AC rule. This does raise questions about what happens after the backstop, but we do not address these issues in the present research.

With the MOC rules the marginal capital cost and user cost components shrink after capacity expansions because the preceding investments are no longer marginal for pricing purposes. In fact, after the investment in the backstop technology the marginal capital cost and user cost components of the MOC rules disappear because there are no further capacity increments planned. Consequently, MOC prices will remain significantly lower than the AC prices after the backstop technology until the system is "paid-off" with the AC rule.

Net Revenues

Present value net revenues from the AC pricing rule are zero due to our break-even constraint. A break-even factor was applied to the revenue requirements to ensure that any water use responses to price changes were compensated by price increases until the system reached equilibrium with net revenues over the planning horizon equal to zero. The estimated break-even factor increases over time and reaches a maximum in 2030 (see Table 5). This suggests that revenue shortfalls from (the lack of) price changes will tend to compound over time. Given the substantial amount of investment activity over the planning horizon, the AC pricing policy would have to be continually revised to ensure solvency.

Annual net revenues from the MOC pricing rules are given by the revenues generated from water sales (and the fixed fees for environmental mitigation expenses in MOC1) less the operating expenses and any capacity investment that occurs. *The capital investments are not financed*, i.e. the cost of capacity increments are due in the year they go on-line. Subsequently, there are huge deficits in capacity expansion years. In other years, positive net revenues are recorded, due to the marginal capacity cost and user cost elements, that should be enough to cover the costs of capacity and operations for the planning horizon in total. In practice, a financing and/or revenue stabilization fund could be used where revenue collections don't correspond with investment expenses (Chesnutt, McSpadden, and Christianson). Russell and Shin (1996b) note that manipulations within a two-part tariff could also handle this situation.

Table 5. Net Revenues to the Regional System

	Average Cost Pricing			Marginal Opportunity Cost Pricing		
year	revenue requirements	break even factor	net revenues	MOC1	MOC2	MOC3
1996	$5,414,223	1.000	($0)	$19,418,809	$19,390,702	$24,301,320
1997	$5,848,141	0.968	($0)	$19,613,862	$15,730,930	$20,803,946
1998	$8,367,954	0.978	$0	($5,503,336)	($9,425,600)	($3,957,896)
1999	$17,505,207	0.993	($0)	($76,294,223)	($79,560,443)	($74,086,130)
2000	$17,671,274	1.000	$0	$18,543,932	$16,867,633	$22,851,960
2001	$29,104,971	1.009	$0	($86,439,534)	($89,879,073)	($84,270,689)
2002	$29,317,540	1.015	$0	$21,155,476	$19,312,242	$25,408,872
2003	$34,341,890	1.006	$0	($16,563,964)	($18,619,602)	($11,550,144)
2004	$51,617,907	1.009	($0)	($85,702,741)	($89,948,005)	($84,406,985)
2005	$53,386,872	1.017	($0)	$22,028,274	$17,473,414	$23,879,483
2006	$55,142,398	1.021	$0	$25,213,402	$20,333,938	$27,680,062
2007	$55,995,893	1.032	($0)	$26,928,976	$26,758,107	$34,578,366
2008	$56,451,062	1.041	($0)	$29,138,475	$28,953,339	$37,427,644
2009	$56,905,190	1.044	$0	$31,517,547	$31,321,328	$40,502,069
2010	$57,358,294	1.047	($0)	$34,082,758	$33,875,205	$43,818,859
2011	$69,656,611	1.053	($0)	($31,576,631)	($31,781,073)	($23,234,326)
2012	$70,143,386	1.058	$0	$18,374,658	$18,272,456	$27,615,554
2013	$70,629,283	1.060	($0)	$19,861,798	$19,751,113	$29,870,375
2014	$71,114,316	1.062	($0)	$21,466,118	$21,346,263	$32,304,238
2015	$71,598,498	1.065	($0)	$23,196,636	$23,066,871	$34,930,980
2016	$72,068,406	1.067	$0	$25,023,667	$24,883,422	$37,706,157
2017	$72,527,935	1.070	($0)	$26,997,990	$26,846,433	$40,706,557
2018	$72,986,713	1.073	$0	$29,124,638	$28,960,875	$43,939,982
2019	$73,444,749	1.075	($0)	$31,415,100	$31,238,167	$47,424,034
2020	$73,902,052	1.078	$0	$33,881,708	$33,690,565	$51,151,246
2021	$74,710,173	1.079	$0	$37,071,700	$36,862,343	$55,962,309
2022	$75,630,911	1.081	$0	$40,425,222	$40,196,048	$61,016,222
2023	$76,549,048	1.084	$0	$44,033,896	$43,789,271	$66,494,948
2024	$120,669,197	1.094	($0)	($119,993,423)	($120,189,295)	($120,138,303)
2025	$122,216,898	1.105	($0)	($0)	$0	$0
2026	$123,378,256	1.109	$0	($0)	$0	$0
2027	$122,091,668	1.112	$0	$0	($0)	($0)
2028	$114,313,830	1.115	($0)	($0)	$0	$0
2029	$115,503,322	1.117	$0	$0	($0)	$0
2030	$107,025,652	1.119	$0	($0)	$0	$0

Present Value Net Revenues ($1996)	($0)	$3,214,902	($19,485,576)	$78,800,757

Table 5 shows that for the MOC rules the surpluses recovered in non-capacity years do not evenly match deficits in capacity years to generate positive present value net benefits every case for the planning horizon. To begin, the MOC3 rule generates positive, often rather large, present value (1996$) net revenues. The surplus revenues are due to the user cost component which more than offsets any losses due to water use responses to price changes and the lumped investment bills. Technically, though, the user cost revenues are rents to the state, not necessarily to the water supplier. Martin et al. note that such excess revenues "could be used to provide other social services, such as compulsory education, for which society has decided that the social benefits obviously exceed that private costs" (p. 51). The MOC2 formulation does not have the user cost component and generates relatively lower revenues with negative present value net revenues over the planning horizon. The same is true of the MOC1 formulation, although, it shows present value net revenues that are positive because environmental mitigation costs are collected in fixed fees and, thus, do not contribute to price change response induced revenue losses.

Net Benefits

The analysis of the potential net benefits available from a switch to MOC pricing are estimated in terms of single family household customers. The net benefits of a move to efficient MOC pricing are figured as resource or opportunity cost gains (losses) less any losses (gains) in annual consumer surplus per an average single family household (given by area C in Figure 2). With this welfare measure, the net community gains per household are greatest where the estimated MOC efficiency price is significantly higher than the AC price. The simulated price paths show that the difference between AC and MOC is greatest just before (or after) capacity expansions. Subsequently, the net benefits from pricing reform should be clustered around (before) capacity expansions.

Figures 4 and 5 summarize the distribution of net benefits available over the planning horizon from a switch to MOC prices in the study area. The present the net benefits of a discrete switch in any given year is presented in Figure 4. The net benefits are significant and appear to peak just before capacity expansions and fall thereafter. Further, the MOC3 formulation offers the greatest net benefits, followed by MOC2 and MOC1. These findings alone, however, don't really suggest much about the "optimal" time to switch to MOC pricing.

Figure 5 shows the present value (year t$) of anticipated total benefits from a *permanent* switch to MOC pricing. Net benefits are a maximum at the beginning of the planning horizon in 1996 and decline, with periodic "humps", until 2030. The results imply that the sooner the switch to MOC pricing the better, but there will continue to be net benefits available throughout the planning horizon until the backstop technology is in place.

Note that the increase in investment activity at the end of the planning horizon creates greater present value net benefit opportunities in the latter half of the planning horizon for MOC1. This suggests that latter period switches to MOC pricing may be at least as beneficial as an early switch. The benefits of latter switches, however, should be taken with caution because as new capacity is accumulated, annual debt service payments will pile-up with AC pricing. The annual debt service does not disappear with a move to a MOC policy and will have to be collected somehow, in which case there is pressure to maintain the AC rule. To sum up, where the switch to MOC pricing is being contemplated and water supply costs are on the rise like in the study area, an earlier switch is preferable to a latter one.

Figure 4. Net Benefits of a Discrete Annual Switch from AC to MOC Pricing

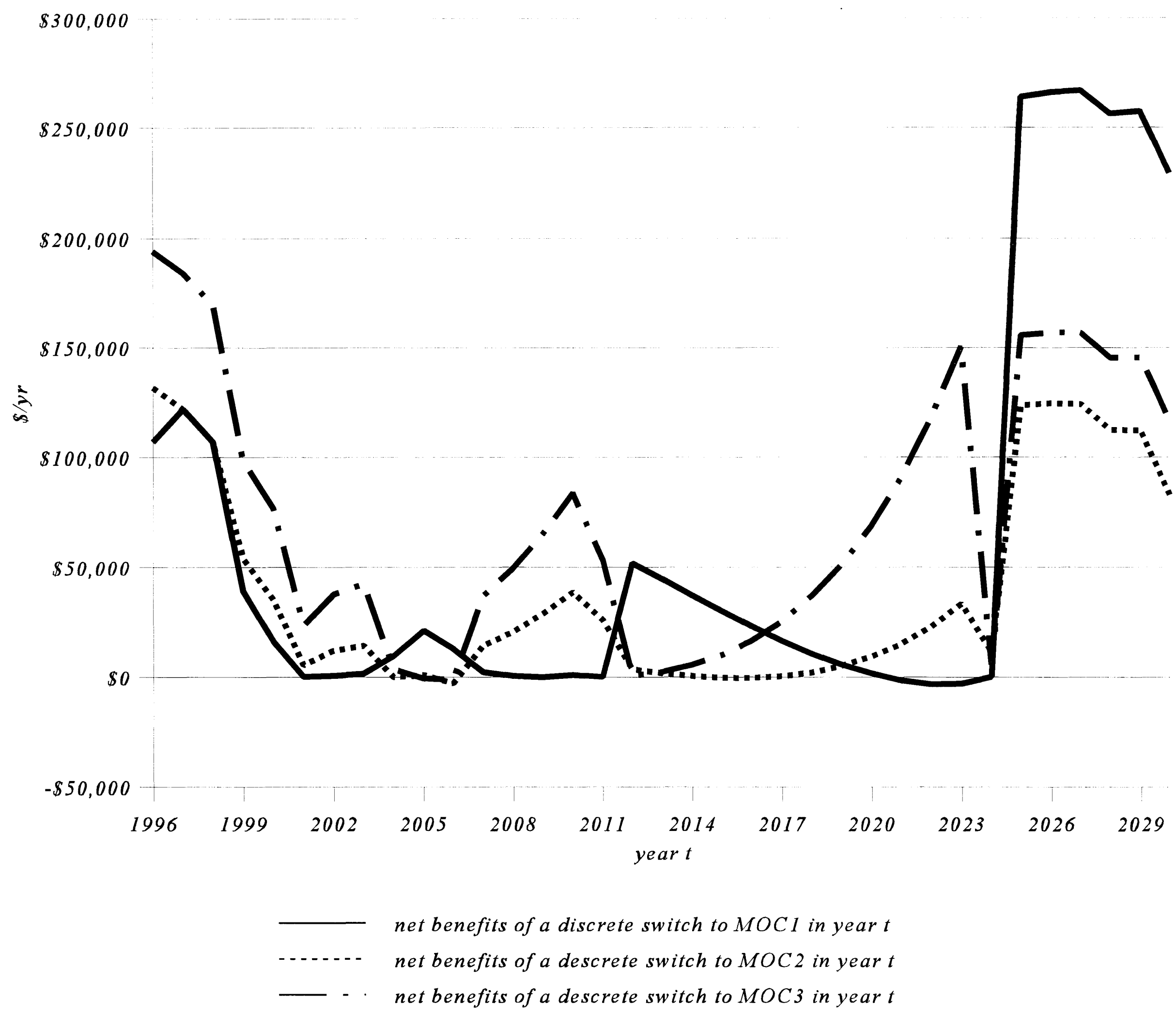
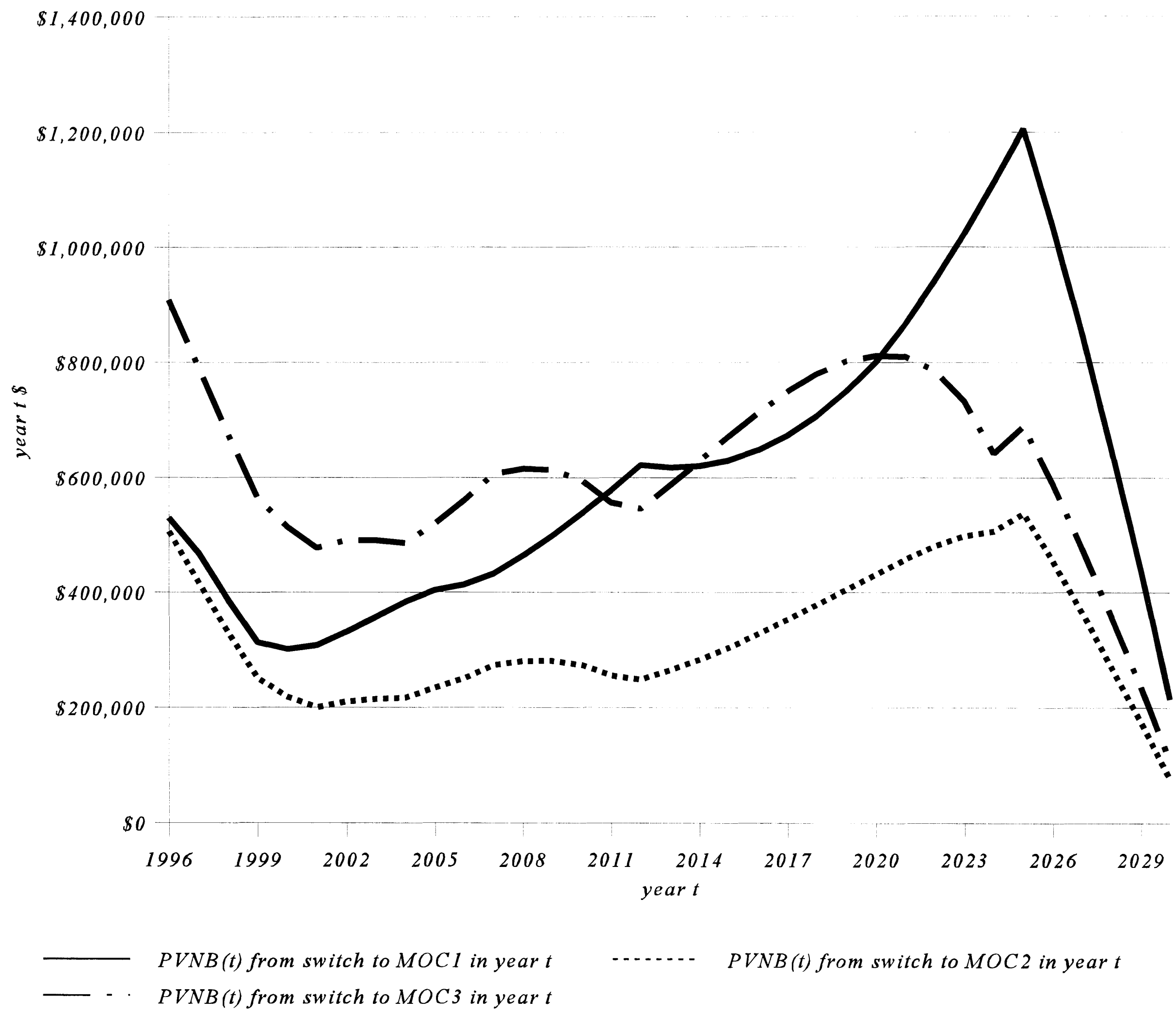


Figure 5. Present Value Net Benefits of a Permanent Switch from AC to MOC Pricing



Endnotes

1. In the more usual case where a utility serves more than one customer group (e.g. residential, commercial, industrial, etc.) with nonuniform (peaking) demand patterns, the portion of shared debt service cost 'attributable' to each demand service level and customer group and must be determined. The allocation of costs to customer classes (services), however, is inherently arbitrary (Baumol, Koehn, and Willig; Braeutigam) due to the prevalence of shared costs in water service production (Stack 1996).

2. Markets for wholesale water, on the other hand, do appear to be quite responsive to changing market conditions, though price fluctuations may not accurately reflect changes in resource values due to externalities, uncertainty and imperfect information. (Saliba et al.).

3. The TVMC formulation produced wild price fluctuations in earlier simulations with the capacity expansion plan in the present study.

4. A thorough discussion of the AMC and the other marginal capital cost formulations for water service is found in Russell and Shinn (1996a,b).

5. The external costs can only be considered approximately internalized because mitigation costs are taken as a proxy to the true external costs that would be revealed with a damage function.

6. This is a fairly accurate characterization where long time horizons are contemplated because the "used and useful" criterion tends to restrict the amount of "future" costs allowed in current prices (Deloite and Touche). In shorter time spans (less than two years), however, construction funds (CWIP) and margin reserve allowances tend to blur timing considerations.

7. This capacity expansion plan represents the anticipated future water supply needs based on a 50% reduction in groundwater pumping phased in at ten percent a year from 1997 and 2007 at

all wellfield permits in the region. Further discussion of the wellfield pumping restrictions is presented in Carter and Milon (1998).

8. See Carter for details on the wholesale-to-retail price conversion

9. The unit cost for backstop water is measured as the predicted total *system-wide* marginal operating and environmental cost with the backstop included, which may be more or less than the marginal operating and environmental cost of the backstop technology alone. This accounts for the mixing of supply source costs as the marginal costs of the backstop are blended with the rest of the system costs.

10. Commercial demands were modeled in the study using a constant price elasticity of -.25 and it was assumed that multi-family residences do not adjust their usage in response to changes in water prices (Brown and Caldwell in association with John Whitcomb).

11. For the case study, these variables are set to reflect an average household's 1995 base water use in the study area.

12. The price variable is estimated as the sum of marginal sewer price and a potable water price that is "ramped" between pricing blocks. The (border) price along the ramp between blocks is essentially an average of block prices weighted by the portion of consumption (of each household) occurring within each block. This option provided greater explanatory power than both average price and marginal price specifications (Brown and Caldwell in association with John Whitcomb).

13. The details of the aggregation procedure are available in Carter.

14. There were attempts to proxy income which was not available by separating demand and elasticity estimates for low, medium, and high property values. The initial analysis found

differences in elasticities among property values, however, subsequent work (Whitcomb) showed that these differences are not significant. The medium property value coefficients are used in this study.

15. The incremental rise in AC prices in the years prior the large capacity expansion in 2002 is the result of several consecutive smaller capacity increments and is therefore coincidental.

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