Distributing Water's Bounty

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Abstract

Following an investigation of theoretical issues and an inventory of modeling requirements, support for increasing block rates is examined empirically, through comparison to a uniform rate that includes scarce water value. Using a single-year, monthly simulation model, it is found that under conditions of scarcity, households using smaller amounts of water are better off with a uniform rate than an increasing block. Large water users have opposing preferences. Similar results arise for those household characteristics which are correlated with water use, such as income, property value, number of residents, and outdoor area of the property. For example, low-income households prefer scarcity-inclusive uniform rates over increasing block rates when scarcity is present. Therefore, in contrast to popularized opinion, increasing block rates do not place the welfare burden of conservation on large water users, nor do such rates favor low-income people in scarce-water circumstances.

Keywords: water rates, water pricing, block rates, uniform rates, water conservation

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1. Introduction

For ordinary commodities, considerable economic surplus may be generated, without which there is no motivation for production or exchange. The same is true for processed water. Although popularized perception is that people pay for piped water to their homes because they need it, in truth they pay for piped water because this approach has yielded more household surplus than containerized delivery or self-supply of water. Economic theory distinguishes three forms of surplus according to the receiving agent. There is consumer surplus, measured either in exact/Hicksian ways or approximated in the Marshallian way (Johansson 1991). Second, there can be producer surplus where scarcity rent (Heal 2007) as well as the typical quasirent can accrue to suppliers (Just, Hueth, and Schmitz 2004). Lastly, net government receipts, which can be dispersed as water supply subsidies, are distributed across a population overlapping with consumers and producers. Processed water is unique because of the high degree to which these surpluses may be channeled to water consumers, depending on the institutions governing the situation. The crucial institution is the system of water rates that distributes water's accumulated surpluses – what may be thought of as water's *bounty* – among consumers.

In the literature of water resource economics, institutional advance is an accented strategy for influencing surpluses and motivating agent behaviors that are better aligned with resource scarcities. Important literature threads address the following three themes. Water market creation through property right assignments in natural (unprocessed) water is intended to enhance reallocation by entitling water right owners to scarcity rents (Milliman 1959; Anderson and Hill 1997). Water utility privatization conveys producer surplus as a regulated profit which is hoped to induce cost-effective operations (National Research Council 2002; Barraqué 2003). Water rate reforms reposition consumer surpluses as a mechanism to coax water-conserving behavior from the clients of urban utilities and irrigation districts (Herrington 1987; Massarutto 2007; Bar-Shira and Finkelshtain 2000).

The analysis pursued here – exploring the welfare impacts of increasing block rates – lies within the third theme. In the coming sections, the broader theory and character of this topic is examined, prior to establishing numeric evidence via a simulation model that contrasts increasing block rate (IBR) and uniform rate (UR) systems for their effects on consumer-received surpluses. The analytical setting emphasizes the commonplace, developed-country situation where: (1) the water utility is either a not-for-profit, publicly managed entity or profit is received by a private operator in a lump-sum manner (as occurs when regulated profit is a constant rate of return upon a constant capital level); (2) the water use entitlements implicitly or explicitly held by the utility are unaccompanied by payments to a separate class of water right owners; and (3) a user-pays principle dictates that the utility does not receive subsidies and must therefore generate sufficient revenue to offset the costs of water service. An important empirical finding is that IBR systems can injure low income or small water consumers and raise the welfare of high income or larger consumers under conditions of water scarcity, thus indicating that IBRs may be an inequitable path to achieving inefficient water allocation. Inequity is a new result.

2. Reconfigured Surpluses

The influence of water rate selections upon the surpluses received by water consumers of differing characteristics is a unique topic. Economic efficiency in water use is not well championed by contemporary rate policies, and market determination of retail water rates is not a viable option, due to the natural monopoly character of water service. Within this environment, rate policy is often determined by local stakeholders and their political representatives. They bring questionable ideals about water into the rate deliberation process plus the usual self-interest combined with weak or absent economics training (Kelso 1967; Boland 1987). For example, the "free-good image of water" perpetuates a failure to acknowledge water's value in pricing decisions (Kelso 1967, p. 180).

While evidence indicates that price policy is more effective than regulatory means of promoting conservation (Grafton et al. 2011), communities are sluggish to adopt such findings in policy, largely due to presumptions that such price changes harm ratepayers and current ratepayers should not be harmed (even when it is in their future interests). Unfortunately, welfare analyses of proposed policy revisions are seldom performed. Indeed, rate policy rarely receives even after-the-fact investigation of its effects by instituting authorities. Thus, while efficiency is an oft-mentioned goal in rate-making forums, this continues to be disingenuous. In spite of its advantages in recognizing all resource values collaboratively, economic efficiency is commonly set aside in decision-making about rates. When efficiency is discussed, water-centric (i.e. partial) performance measures such as water use per capita are customarily referenced, thereby failing to consider differential consumer preferences across the population and the many applicable resource costs (including water's opportunity costs).

IBRs are demonstrably inefficient because different consumers face different marginal prices with IBRs even though consumers' marginal costs are the same (Edwards 2006). Yet many communities find IBRs appealing and their use is spreading. Not only do IBRs appear fair, but their widespread adoption is reassuring for communities grappling with rising scarcity and looking for promising policy responses. Unfortunately, in addition to causing inefficiency, the design of block breaks and different block rates invites notable ad hocery, and IBRs perplex consumers as they make water use decisions. Furthermore, rate increases respectful of water value for all consumers, as commended by economic principles when scarcities arise, are rarely within the capacity of democratic processes (Boulding 1980) while it sometimes politically feasible to raise rates for abnormally high users or wealthy users.

In spite of these issues, leaders who adopt an IBR commonly feel that they have acted in the public interest to curtail water use. IBRs have a progressive appearance, because they seem to place higher burdens on higher income households (Monteiro and Roseta-Palma 2011), but their performance in this regard may be compromised by particular features of water service and policy. In comparing IBRs to their main competitor – uniform rates styled as two-part tariffs – it should be recognized that both IBR and UR systems distribute more than ordinary consumer surplus across the service population. First, in locales where a scarcity of naturally occurring water exists, scarcity rents are usually allocated to resource *users* as opposed to being received by resource *owners* (unlike most resources). Hence, receipt of these rents may be proportional to use, inferring greater gains for greater users. Second, in the dominant supply setting where the water utility is a publicly owned, nonprofit operation, producer surplus is not supposed to occur. As a consequence of these conditions, the selected rate system is performing not only a rationing task for scarce water (and capital, energy, etc.), but it is simultaneously allocating multiple surpluses across consumer groups. Ordinary consumer surplus, quasirents, and scarcity rent are allocated to consumers unless corruption or appropriation by the utility or government somehow intervenes. This magnification of consumer-dedicated surpluses is a unique facet of water provision, amplifying the consequences of rate selection. Failure to consider these conditions risks perpetuating inefficient policy, and it is conceivable that such policy will be disappointing for its equity implications as well.

3. The Challenges

There are several important factors convening to determine the efficiency and equity of a given water rate system. Key among these are the natural monopoly character of water service, communal or state ownership of the water resource in its natural state, the high dimensionality of feasible rate packages, and the imperfect consumption-price information applied by most consumers in resolving their water usage.

3.1. Natural Monopolies

Water transmission, treatment, and distribution are renowned for their capital intensity (Hanemann 1998). This condition recommends a single supplier, giving rise to the classic situation where average costs exceed marginal costs at the level of quantity demanded (Sibly 2006). Among the rate design consequences is that a single price for water cannot simultaneously recover all operational costs and equilibrate demand and supply. This is an unsurprising as well as problematic result, for we are essentially asking water price to ration both scarce/expensive capital (infrastructure) and possibly scarce water. Under a user-pays doctrine where external subsidies (or conceivably sinks for excess revenue) are not permissible, the available remedies require complications of rates. Historically, declining block rates were of assistance in addressing this problem, but managers' first-choice tool for balancing utility budgets has always been a nonvolumetric fee because of its revenue reliability and administrative simplicity, sometimes in combination with a volumetric water price and other times alone. Indeed, it is the volumetric instrument which is the younger addition to rate policy.

As communities expand in size and approach the physical limits of readily available water, they may encounter scarce water conditions to accompany the infrastructure challenges. This is when the absence of volumetric rates or the continuation of declining block rates may be questioned by decision makers, and experimentation with new rate structures may commence. Egalitarian-minded and environmentally oriented communities are often attracted to IBRs at this stage. Another consequence of water scarcity is the emergence of scarcity rent, which must also be allocated among consumers when it is not appropriated by water right owners or the water utility. Whereas the increasing returns to scale that tends to define natural monopolies implies that marginal cost pricing will generate insufficient revenue, the emergence of scarcity rent is an opposing force insofar as its incorporation into rates tends to generate revenue in excess of utilities' financial costs.

3.2. Public Ownership of Natural Water

A central feature of urban water supply is often a property rights doctrine espousing public ownership of natural water resources. Under either state ownership forms such as water abstraction permits or common property forms such as riparianism, individual utilities do not hold an exclusive and transferable title to specific amounts of the water resource (Scott and Coustalin 1995). The legal rule in these cases is that water processors' entitlements to water are usufructory, meaning that the utilities can withdraw water and pass it to ultimate consumers for their benefit, but the utility cannot extract benefits except through the water use of its clients. In particular, the utility cannot transact its entitlement to others nor buy/lease quantities of water rights from others. A water utility may, however, be able to contract with water wholesalers such as water authorities or districts for water access or deliveries, yet these entities operate within the same water right regime – therefore basing observable contract "prices" on their own costs of operation, exclusive of any true water scarcity value.

Under these conditions, an explicit value is rarely assigned to represent water's opportunity cost, as idealized in the economist's notions of the marginal value of raw water for surface water or the marginal user cost of ground water (Griffin 2001). Scarcity-inclusive, processed water pricing will occur only when a utility acknowledges the value of its entire water right inventory, regardless of whether this inventory causes new cash outlays in any given fiscal period. For example, incorporation of opportunity costs takes place when a utility observes the going rental price of natural water in its region's water market and then includes an appropriate transformation[1] of that price in its water rates.

Absent such opportunity costs in rates, as is the normal omission worldwide, consumers are receiving errant signals and they are receiving scarcity rents (though in inefficient amounts) proportioned by their water use. Consumer-received surplus is broadened in this case. Also, water use is overstimulated by the consequent underpricing of processed water. In the rare cases where a volumetric rate might include a scarcity-based opportunity cost, the nonprofit utility must disperse the scarcity rent it is receiving to avoid making a profit. There are multiple policy avenues for achieving this. Most of them tempt injuries upon some aspect of allocative efficiency.

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[1] Transforming calculations can include multiple adjustments, such as differing units of measurement or the conveyance losses incurred in delivering water.

3.3. Rate Dimensionality

Methods for dispersing rents (quasi- and scarcity) as consumer surplus are coupled with rate design; the IBR vs. UR question highlights two of the more noteworthy options. Not all options for dispersing rent and balancing utilities' budgets are rate-based however. In the interest of completeness, and including the IBR and UR options, the following possibilities can occur in various degrees and combinations within contemporary utilities.

- One method of rent dispersal, set aside in the forthcoming analysis, is that the utility's water production activities may be conducted wastefully, i.e. other than least cost. Inputs can be incompletely employed or unfortunately combined. Factor owners selling their products or labor to water suppliers can be paid in excess of their contributions. Production can be poorly organized. In addition to failing to be least cost, efficient service levels can be underachieved as occurs when consumer desires for reliable and healthy water deliveries are unsatisfactorily met. These deficiencies might be better controlled in competitive environments where weak performances tend to be eliminated, yet they are sustainable in natural monopoly settings. The privatization question arises for this reason. Yet, it is also possible for privatized suppliers to earn supranormal rewards or to operate inefficiently so as to disperse rents in their favor. Waste can also occur when system objectives are overachieved, given that public utility managers are strongly motivated to pursue water supply reliability (Lach, Ingram, and Rayner 2005). When water managers have discretion over expenditures, as is common, and are able to pass all reasonable costs on to consumers, they may overspend so as to make the water system overly reliable, thereby easing their exposure to infrequent but troublesome tasks. Costs and reliability can be inefficiently high as a consequence, inferring loss of aggregate welfare.
- Another dispersal method, also set aside in the forthcoming analysis, is to give new users subsidized access to existing surpluses. When surpluses are treated as an open access resource, as occurs when new users are not required to pay cost-mitigating entry fees, new

entrants lower the gains being received by existing users. In water-scarce areas these bounty crashers take surplus from existing users because they typically trigger (1) accelerated water supply-enhancing investments to harness additional water resources and (2) expansion of the water treatment/delivery system. The first of these costs can be markedly higher than historical costs in a scarce-water era. When the combined costs of entry outweigh entry fees, as is the usual scenario, the deficit is implicitly funded by existing users through declines in the amount of surplus they receive.

- IBRs disperse rent and recover costs through multiple rate elements. These components of rates become interrelated when utility budgets must break even. The application of lower prices to small consumers has a superficial similarity to progressive taxation wherein high water users (and perhaps higher income consumers) pay higher shares of total costs. Thus, prevailing opinion is that surplus distribution under IBRs favors low water users. Interactions with other rate elements, however, raise significant questions about whether this is an accurate perception.
- URs use a single nondiscriminatory water rate for their volumetric instrument. If this rate is set to the efficient, marginal-cost level, all the usual rents (quasi and scarcity) can become embedded in other rate elements, especially the recurring, flat "meter" fee.[2] The embedded rent is a preliminary indication that URs distribute particular rewards more or less equally across connections, independently of water use levels, unlike IBRs.

3.4. Demand Responses

Discussions about water rate-making will sometimes call attention to the price inelasticity of water demand and use this attribute to steer the rate choice away from common economic doctrine. Indeed, the old-school, water manager perspective was that water demand was far too inelastic for volumetric pricing to contribute anything to policy. Consumers were said to have

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[2] This fee is called other names, depending on region or tradition. Regardless of label, it is recognizable as the fixed minimum charge that is part of every household's water bill in every billing period.

water needs that are unresponsive to price. Recent attitudes are less polarized and more accurate, but water demand inelasticity remains highly emphasized. Contemporary statements about water's price inelasticity are often that (1) inelasticity requires large price increases to exact meaningful consumption responses and (2) such changes may involve substantial rises in water bills. When these concerns have both truth and merit, major income transfers may accompany efficient rates, perhaps turning efficient rates into a system of regressive taxation rather than fulfilling the efficiency role they are intended to perform. This may be an important concern, yet it is also the case that price inelasticity of demand is a common condition not confined to water. For example, most food items also exhibit inelastic demand. Hence, inelasticity is insufficient grounds for ignoring efficiency prescriptions.

A possible escape from the downside of water demand inelasticity is to return, in a lump-sum manner, the utility's "excess" revenue that arises from charges for opportunity costs. Lowering the meter fee – the second part of a two-part UR – is a touted strategy for accomplishing this (Griffin 2001, 2006; Sibly 2006; Grafton and Ward 2008), but to do so activates two further considerations. First, although an increased water price will lower quantity demanded, the lump-sum return of excess revenue from the "average consumer" to a specific consumer may cause a positive increase in consumption via an income effect. Anticipating and modeling this effect is hence desirable. Such modeling is achievable, especially given the many demand studies that have estimated both price and income elasticities (Dalhuisen et al. 2003).

Second and more problematically, it is well documented that typical consumers do not respond well to water's marginal price (Gaudin 2006). Instead, they may respond more, in a statistical sense, to price perceptions that consumers can more easily formulate. The most evident price index is average price, which contains both the volumetric price plus all lump sum or inframarginal aspects of the rate package. If consumers drive their conservation behavior by reacting to average price, an increase in marginal price accompanied by an decrease in meter fee will have a masked appearance to typical consumers. If consumers respond perfectly to average price, only low and high water users will discern a change in average price when marginal price and the meter fee are simultaneously changed in opposing directions, thereby muting the community's response to seemingly clever rate changes. Therefore, the selection of a price driver (marginal or average) is an important consideration when modeling proposed rate reforms. Given the absence of prior studies, it is useful to perform analyses using both drivers at this time.

4. Equity and Efficiency Prescriptions

4.1. Efficiency in Rates

Different advice for rate-making emerges for different settings as well as from various goals. Efficiency prescriptions would be narrower were it not for the dueling tasks of managing both capital and water (Massarutto 2007). The extraordinary dominance of fixed costs in the water industry favors fixed fees as is accomplished with meter fees. Moreover, the unallocatable character of much of these fixed costs implies that equal fees or discriminatory fees across customer classes can be similarly efficient. Yet, a large proportion of capital costs are caused by peak loads, with some infrastructure resting idle much of the time. If volumetric rates can signal in a manner that shaves peaks, then there is a reason to apply volumetric rates to reduce capital costs. Moreover, both energy and water opportunity costs may accentuate the attractiveness of seasonal volumetric rates, due to coordinated seasonality in these costs. This may have slight implications for the rate structure selection emphasized here, because IBRs and URs appear equally capable of expressing seasonally differentiated signals.

Looking beyond peaking issues, the main efficiency comparisons favor URs. When the potential Pareto goal of maximizing communitywide net benefits is formally applied, the results replicate the long-known efficiency prescriptions that price for all users should equal marginal cost and that marginal cost include any applicable opportunity costs stemming from scarce water (Griffin 2001). Here, the favored marginal cost concept is that of long run marginal cost, because of desires to foster efficient selections of durable goods (e.g. water-using appliances and landscaping) by consumers. Optimal sizing of the water supply system is supported too. For short term policy, where capital costs are invariant, short-run marginal cost pricing is the leading concept. URs are better aligned with these ideals, because at any moment or any level of community water use the marginal social cost of all customers' water use is essentially identical. While a consumer of small amounts of water is less costly to serve in terms of total costs, their marginal costs are no different than that imposed by large users.

4.2. Equity in Rates

What is or is not a fair system of rates is highly influenced by perspective and context. Commonly, people will protest the "unfairness" of a rate element on the grounds that it runs counter to their personal interests (Jones and Mann 2001). Fairness can also be focused on procedural factors – "did my opinions receive a proper hearing" – rather than outcomes. Boland argues that *equity* in water pricing is an objective criterion equivalent to "the equal treatment of equals," whereas *fairness* is subjective (1993, p. 8). Some aspects of these discussions circle back to highlight efficient water rates as equitable rates, because efficiency is in the community's interest and all water consumers are similarly situated as community members who cause the water utility to make expenditures on their behalf (Boland 1993; Jones and Mann 2001). Efficient water pricing is also argued to be necessary for sustainable water use when sustainability is viewed as intergenerational welfare preservation (Bithas 2008).

Regardless of formalized definitions pertaining to fairness, the emerging dominance of IBRs as the rate system of choice is prima facie evidence that IBRs are thought to be fairer than URs. As communities explore options, often by investigating what similar cities are doing in their region, they discover rising interest in IBRs and may themselves become attracted to the IBR template. The basic ideals of low rates for low consumers and high rates for water "wasters" are compelling in the absence of economics training. The greater economic efficiency of URs tends to be overlooked in community decision-making processes, and loss of simplicity and transparency with IBRs may be regarded as a small matter. The inefficiency of IBRs is weakly understood as are other disciplinary ideals for water pricing (especially scarcity values). Decision makers like to be problem solvers, and block rates appear to be a fair solution.

Yet, it can be acknowledged that the impact of rate selection on consumer welfare is better measured by water bills than by water rates and is much better measured by received net surplus. As illustrated in the next section, IBRs convey "inframarginal surplus," but URs do not, and the only way for a consumer to gain all of the inframarginal surplus embedded in an IBR is to consume in the highest block. Hence, higher block consumers get more inframarginal surplus than lower block consumers. In addition, the balanced budget requirement of rates infers that the flat meter fees will be affected by rate choice, and these constant elements of water bills can have a dominant influence on the bills faced by low water users.

4.3. A Basic Model

To capture the dimensionality of rates, let $R=\{M, (w_1,r_1), (w_2, r_2), ...\}$ be a fully described rate package having a recurring, fixed fee of M as well as block rates where rate r_i comes into play at water use level w_i and continues until $w=w_{i+1}$. If R is complete in the sense of fully describing bill computations for all consumption levels, then it is required that $w_1=0$, and the last listed rate applies to arbitrarily large consumption levels.

With this notation, $R_{ur}=\{M_{ur},(0,p_2)\}=\{M_{ur},(0,mc)\}$ represents a UR that charges a monthly meter fee of M_{ur} and then a marginal-cost price of p_2 for every unit of water exceeding 0 units.[3]

An alternative system is $R_{ibr}=\{M_{ibr},(0,p_1),(w_2,p_2)\}$ with a meter fee of M_{ibr} and two blocks. The first block establishes the price p_1 for the block that runs from 0 to w_2. The second block price is p_2 which is assumed to be identical to the UR system, R_{ur}. Of course, the UR and IBR systems need not overlap precisely over the second block, but by briefly adopting this assumption we can easily witness basic characteristics of the two systems.

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[3] Many communities grant a small amount of "free" consumption – essentially an IBR system where the first block price is zero.

Inframarginal surplus can be defined as that portion of the consumer's net benefits which is attributable to paying below-system-marginal-price rates for a portion of water use. IBRs tend to disperse more net rents as inframarginal surplus. Moreover, the distribution of inframarginal surplus among all consumers raises the revenue that must be generated by other elements of the rate package. As a consequence of the IBR's inframarginal surplus and the fact that p_2 is the same for both systems in our example, it must be the case that M_{ur} is exceeded by M_{ibr} if both rate structures are to be budget balancing. Thus, defining ΔM as the difference, it is known that $\Delta M = M_{ur} - M_{ibr} < 0$.

Both rate systems along with the demand schedules of two representative consumers are exhibited in Figure 1. Assuming two well informed and rationally behaving consumers, A and B, observe that the inframarginal surplus (for the IBR case) received by the low-demand consumer (A) is area b whereas that received by B is the maximum possible (area b+d). Under the IBR the total received surplus (consumer surplus plus quasi/rent surplus) is $a + b - M_{ibr}$ for A and $a + b + c + d - M_{ibr}$ for B. Using the portrayed information, a policy switch from R_{ur} to R_{ibr} brings the following surplus changes for consumers A and B.

$$\left.\begin{aligned} \Delta S^A &= S^A_{ibr} - S^A_{ur} = +b + \Delta M \\ \Delta S^B &= S^B_{ibr} - S^B_{ur} = +b + d + \Delta M \end{aligned}\right\} \qquad (1)$$

As ΔM is negative, the sign of both surplus changes appears ambiguous. Yet, the fact that consumer B gains an amount that A does not (area d) is revealing. If the switch from the UR to the IBR happens to be surplus neutral in the sense that communitywide gains or losses do not occur, and if A and B are representative of consumers in their positions, then we might approximately expect that $\Delta S^A + \Delta S^B = 0$. With the results of (1) above, this implies that the smaller consumer loses as a result of the shift to the IBR while the larger consumer gains.

Based on this first inspection, IBRs must be carefully designed if goals are to reduce water use without harming type A consumers. Otherwise IBRs cannot be the friends of small consumers. In the search for remedies, IBRs with more than two blocks are not immediately helpful; this only exacerbates the losses incurred by first block consumers while adding layers of inframarginal surplus to be gained by high-block consumers.

The main avenue for reversing the above impacts of IBRs on consumers is to select a greater-than-marginal-cost, second block price: $p_2 > p_{ur} = mc$. This would alter the behavior of type B consumers and also reduce their received surplus, thereby lowering M_{ibr} and potentially aiding type A consumers. If p_2 exceeds mc sufficiently, then a move to a two-block IBR will not harm a representative A consumer. However, if the switch to the IBR is meant to harm no consumer in the initial block, then particular attention has to be devoted to very small consumers whose bills are dominated by meter fees. At the same time it must be acknowledged that discrepancies between p_2 and marginal cost, as required to protect small consumers from welfare loss, aggravate inefficiency in water use. Overall then, not only does it become difficult to belief that IBRs might be approximately efficient, but it may be the case that careful, equity-driven adjustments made upon IBRs to protect A-types will further harm allocative efficiency.

5. Analytical Requirements

The preceding discussion indicates that several elements combine to determine how the net benefits of water service are distributed in a community. Modeling of several interacting elements is required to accurately contrast URs and IBRs. Among the requirements are the following.

- Investigating the effects of rate system changes on consumers of different types involves the classification of "types" and requires supporting data concerning the distribution of these types within a community plus their correlation with other consumer characteristics. Measuring impacts across a water consumer type that is defined by the level of initial water use is most practical, but it may also be important to study surplus-change incidence across income or wealth levels or conceivably other socioeconomic characteristics.
- Demand reactions to alternative rate systems and alternative rate levels should be reasonably modeled. Not only might different consumers have differing reactions, in terms of price and

income elasticities, but there is strong potential for imperfect information to cloud consumer perceptions of rates. Among other challenges, consumers may respond to average price more so than marginal price, as is commonly found by statistical studies. Not only does this complicate behavioral modeling, but it confounds welfare/surplus measurement.

- In the absence of a specific rate-change regime, as might be proposed in a specific city, it is necessary to select a specific parameterization of URs and IBRs to compare. This is more troublesome for IBRs due to their higher dimensionality. There can be any number of blocks, with different lengths and prices to consider.
- When consumers alter water use in response to modified rates, total water consumption is changed. Because some utility costs are variable, there will be changes in the revenue required to operate the utility as production is altered. Therefore, some knowledge of the utility's cost function is required.
- Although weather has been neglected in the discussion thus far, variable weather can be an important influence. Dry weather accentuates excess demand by driving water demands and supplies in opposite directions. This increases water's opportunity cost and scarcity rents, with potentially large effects on each element of a rate structure.

6. Empirical Model Overview

To address these challenges, a city of 1000 representative households of various characteristics is modeled to examine the relative effects of two alternative rate systems. Temporarily omitting the time index needed to represent our month-by-month analysis, each household h demands a water quantity d_h given by

$$d_h = f(R, \gamma_h, C), \tag{2}$$

where

R is a vector of parameters describing the rate system (IBR or UR),

γ_h is a vector of household characteristics (income, number of persons, value of the property, outdoor area), and

C is a weather index.

Total demand is therefore

$$D = \sum_{h=1}^{1000} d_h . \quad (3)$$

Each household's bill is determined solely by the rate system and consumption,

$$\text{bill}_h = g(R, d_h), \quad (4)$$

causing the utility's revenue to be

$$\text{Revenue} = \sum_{h=1}^{1000} \text{bill}_h . \quad (5)$$

A monthly demand function is estimated using household data from four Texas cities. A new sample of 1000 households is also generated from this data. Using this information, we simulate consumption, bills, and revenue for twelve months of a typical weather year. The simulation commences with an average IBR system based on the IBRs currently in place in the four cities.

The exercise is then repeated for a UR system, with two modifications accompanying the altered rate structure. First, the UR system explicitly incorporates a scarcity value for water. To generate fuller results about the effect of scarcity value, sensitivity analysis is performed by using three distinct levels, one of which is zero. Second, unlike the IBR meter fee, the meter fee for the UR is endogenous. A candidate guess for this fee is selected and the entire UR simulation is performed for all households over twelve months. Once total revenue and total water use are calculated, they are compared to those of the IBR system. By assuming the IBR revenue is budget-balancing for the utility, and with a known marginal water processing cost for the utility, it can be determined if the UR is also budget balancing. If it is not, the candidate meter fee is revised in the appropriate direction, and the process is repeated until the meter fee and the scarcity-value-inclusive uniform rate generates a total revenue that matches that of the IBR after adjusting for altered costs of total water supplied.

Once comparable IBR and UR systems are completely specified and their demand effects on all households is determined, comparisons can be obtained with respect to water use and bills. Monthly welfare measures for the change from IBR to UR can also be computed for each household according to

$$\Delta \text{welfare}_h = \int_{w_{ibr}}^{w_{ur}} d_h^{-1}(w)\,dw - [\text{bill}(R_{ur}, w_{ur}) - \text{bill}(R_{ibr}, w_{ibr})] \qquad (6)$$

where d^{-1} is inverted demand.

6.1. Data

Monthly household water use, water rate, income, number of household members, and street address information is obtained from a study of seven Texas communities (Griffin and Mjelde 2000). Income and number of household members is based on survey responses, whereas each city provided rates and household water use data for 1995. To obtain additional housing characteristics, property information is obtained from county property taxation authorities. Necessary property information is not available for three of the cities, so they are excluded. The remaining cities are Flower Mound, Huntsville, New Braunfels, and Victoria. Some data for Huntsville respondents was corrupted, resulting in fewer observations for this city than the others.

Using consumption levels and information from each of the four cities, monthly average and marginal price are calculated for every household. Both water rates and wastewater rates are incorporated in the rate data, because both bills are dependent on metered water usage and consumers are responsive to both rates (Griffin and Bell 2006). Household income was provided by the respondents as categorical (five intervals). Based on the interval frequencies, empirical probability density functions of the expected household income are estimated using the maximum entropy density method described in Wu and Perloff (2007). The estimated mean of the interval corresponding to the income interval provided by the respondent is used as a continuous variable in the analysis.

Assessed values (improvements plus land), square footage of homes and improvements, and lot size are obtained from the county appraisal district.[4] Assessed values are for 1995 for New Braunfels and Flower Mound, whereas the appraisal districts' data commences in 1998 for Victoria and Huntsville. Victoria and Huntsville house values are deflated to 1995 dollars using the house price index from the Federal Housing Finance Agency.[5] Because the index is not published for Huntsville, the average of house price index for three cities in east Texas are used (Tyler, Longview, and Texarkana). Outdoor area is lot size minus the area of the main house, porches, garages, and other additions. Several of the appraisals listed a garage for a specific household but did not provide a size. In this case, the average garage size in the sample is used to obtain outdoor area.

Daily weather data for 1995 are for the airport weather stations in New Braunfels, Victoria, and Huntsville. Because Flower Mound does not have an airport, the Grapevine Dam weather station is used with missing values filled in using the Dallas-Fort Worth airport. A monthly weather index for each location is calculated as

$$C_m = (t_m \bullet (days_m - prec_m))/1000 \tag{7}$$

where m is month, t is mean temperature, days is the number of days in the month, $prec_m$ represents the number of days precipitation above 0.25 inches occurred, and 1000 is for scaling purposes. This index captures varying temperatures, aridity, and differing numbers of days in each month.

Respondents indicating they did not live at the residence in 1995 are dropped from the analysis. All respondents whose address was an either a four-plex or apartment complex are deleted. For those respondents living in a duplex, the lot size is divided equally between the two

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[4] Except for Huntsville the sources are Denton County Appraisal District (http://www.dentoncad.com/index.php?option=com_content&task=view&id=98&Itemid=54), Comal County Appraisal District (http://taxweb.co.comal.tx.us/clientdb/?cid=1), and Victoria County Appraisal District (http://propaccess.trueautomation.com/clientdb/PropertySearch.aspx?cid=13). For Huntsville respondents assessed values and square footage size are from the Walker County Appraisal District (http://propaccess.trueautomation.com/clientdb/PropertySearch.aspx?cid=77), whereas lot sizes are from the City of Huntsville (http://www.huntsvillegis.com/propertymap/default.aspx).

[5] http://www.fhfa.gov/Default.aspx?Page=216 Accessed November 2010.

units. Several respondents are deleted because the appraisal district either had no buildings recorded on the property or improvements were built after 1995. Observations with any missing variables are deleted. The number of respondents by city is 89 for Huntsville, 339 for Flower Mound, 277 for New Braunfels, and 252 for Victoria. Summary statistics for the 957 respondents are provided in Table 1.

A distinction exists between respondents and observations. Because the estimated demand curve is for monthly water use, each respondent has the potential to provide up to 12 observations. Not all respondents, however, are associated with 12 observations. The demand models are estimated in logarithmic form; therefore, all observations with a zero value for any of the variables are deleted. Further, to avoid very large average prices, an observation is deleted if monthly water consumption is less than 1,000 gallons (suggesting occupancy for a partial month). The resulting data set includes 10,711 observations.

6.2. Demand Models

Functional form preference for household water demand must accommodate the forthcoming computational matter of solving for quantity demanded when rates are complex, as in the IBR case. Because linear demand forms are more likely to represent water demand poorly at the data edges, our choice is the log-linear (Cobb Douglas) form. Both marginal price (MP) and average price (AP) specifications are developed to enable two separate simulations. The MP demand model presumes a high level of knowledge by the consumer; it has the advantage of enabling welfare computations because the model can be interpreted as indicating willingness to pay. AP models of water demand commonly conform better to data, but they do not offer a ready examination of welfare effects. Because most of the data's price variations, especially for AP, are attributable to simultaneity with consumption decisions rather than exogenous changes in rates, we favor imposition of assumed price elasticities for both models. We are more ambivalent about imposing income elasticities, yet this too is a reasonable approach given the wealth of prior studies available to guide income elasticity selection.

For both MP and AP models, the general demand form is

$$d_{ht} = \exp(\beta_0) P_{ht}^{\beta_1} N_h^{\beta_2} I_h^{\beta_3} V_h^{\beta_4} A_h^{\beta_5} C_{ht}^{\beta_6} \qquad (8)$$

where

d is metered water quantity during the month (thousand gallons),
h is the household index (1-957 or 1000),
t is the month index (1-12),
P is MP or AP inclusive of wastewater charges ($ per thousand gallons),
N is number of people reported to live in the household,
I is annual household income (thousand $),
V is the assessed value of the property inclusive of all improvements (thousand $),
A is the outdoor area, computed as land area minus building area (acres), and
C is the weather index of eq. (7).

Broad studies of water demand in Texas provide insights regarding income and price elasticities. As reported by Griffin and Bell (2006, p. 70), monthly 1999-2003 data for 730 urban water supply systems (over 39000 observations) regressed with a log-linear form resulted in an income elasticity of 0.101 and an average price elasticity of -0.508. An earlier study using 1981-1985 data for 186 Texas urban suppliers produced an income elasticity of 0.17 and an average price elasticity of -0.39 using generalized least squares and a generalized Cobb-Douglas form (Gaudin, Griffin, and Sickles 2001, p. 408). Using a qualified subset of the 1999-2003 data, Bell and Griffin (2008) report a short-term marginal price elasticity of -0.127, thereby providing an absolute lower bound. Dalhuisen et al.'s (2003) compilation of metadata from prior water demand studies yielded a mean price elasticity of -0.41 (median = -0.35) and a mean income elasticity of 0.43 (median = 0.24). They report no significant differences between MP and AP specifications for either price or income elasticities, and that long-run price elasticities tend to be 0.27 lower (more negative) than short-run elasticities, whereas long- and short-run income elasticities are not significantly different.

Based on these prior studies and our greater interest in long-term welfare and impact analysis, a price elasticity of -0.5 and an income elasticity of 0.15 are imposed upon the demand models, with other parameters estimated by ordinary least squares. Table 2 contains the consequent demand models.

6.3. Simulated Households

Using a procedure similar to that applied by Richardson, Klose, and Gray (2000) and implemented by Simetar® (simetar.com), a multivariate distribution of income, house value, number of residents, and outdoor area is developed using the previously described data set. Income is assumed to follow a negative binomial distribution whereas the remaining characteristics follow empirical distributions. Correlations among characteristics are required to match those found in the original data. From this multivariate distribution 1000 randomly selected households are generated for use in simulation. Because this process yields incomes as low as zero, whereas the lowest recorded income is $15000 in the sample, all incomes are shifted upwards by $5000. General characteristics of these households are given by Table 3.

6.4. The Model Rates

Due to growing application of IBRs, an examination of contemporary rates provides a more interesting basis for defining the IBR to be used in the simulations. For inspiration we look to the rates now applied by the four cities. In fiscal year 2011, all four cities use IBRs for water and all four use winter averaging for sewer rates. For water, the number of blocks used by these cities now range from three to seven, including three instances in which MP=0 for the first two or three thousand gallons. These three cities also charge a zero MP for the first two thousand gallons of sewer service.

Winter averaging of sewer rates implies a zero MP in nonwinter months. Two cities use a three-month winter average, whereas one uses a three low-months average. To ease discussion, the low-month averaging case is treated as another instance of winter averaging. The fourth city uses a four-month winter average. One city also establishes a maximum sewer bill, implying the commencement of a zero sewer MP after a particular level of winter water consumption is reached (interpretable as a region of decreasing block rates). Because water used in winter months is the basis of bills charged in future months, the household's true marginal sewer cost of consuming water in winter months is either 4 times (for three-month averaging) or 3 times (four-month average) the stated sewer MP.[6]

The modeled IBR system is the average of 2011 rates which is then deflated to 1995 price levels. Water and sewer meter fees are unweighted averages across the four cities. For both water and sewer, an initial zero-price block extends to two thousand gallons. Additional water blocks are established according to the average endpoints of successive blocks with averaged MPs.[7] The resulting block endpoints are rounded to the nearest thousand gallons. Sewer rates involve a simple two-block design with a zero price up to two thousand gallons and a second block with a nonzero price. This sewer rates employ a three-month (December-February) winter average.

The candidate water rate has seven blocks because the averaging process causes the candidate rate system to have the same number of blocks as the city with the most blocks. Water MPs for the highest three blocks of the candidate IBR are quite similar ($3.27, $3.31, and $3.35). To simplify this system, the final two blocks are eliminated, and the $3.31 price is assumed for the fifth and final block.

Deflation to 1995 levels can be accomplished using a standardized price index, but water rate increases have been outpacing inflation for at least three decades in Texas. In a study of hundreds of Texas water utilities, Griffin and Bell report that the average price of water, including both water and sewer rates, rose 1.41% yearly from 1999 to 2003 after inflation

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[6] It is doubtful that many households are aware of these implications even when they know that winter averaging is being applied. Yet, communities using winter averaging are not attempting to trick households, so it is reasonable to assume that a policy goal is for households to be well informed about rates and to behave accordingly.

[7] The convention adopted for any model rate on an $[w_i, w_{i+1})$ interval is to average applicable rates for that interval across all four cities. The only exception is to ignore one city's zero marginal sewer price caused by a maximum allowed sewer bill. Due to the use of winter averaging, the effect of this maximum is suppressed, and it is particular to a single city.

adjustments (2006, p. 26). The consumer price index increased 2.4% annually from 1995 to 2011.[8] Assuming that nominal 1995 water rates increased 3.5% annually from 1995 to 2011, the modeled IBR system for simulation is stipulated within Table 4. The result appears reasonable relative to observed 1995 rates, although 1995 systems use fewer blocks. In Table 4 observe that the rate of the highest block is only 50% higher than the first nonzero block rate, thereby constituting a weak water-use penalty as compared to some IBRs witnessed in the new era. However, a moderately increasing IBR is usefully conservative for the purposes of this investigation.

In keeping with the perfect information foundations of the MP demand model, each household is assumed to know its demand and the rate structure precisely. They even acknowledge a quadrupled sewer price during winter and a zero nonwinter sewer price, as is actually the case for these months. The water and sewer meter fees are pure income effects in the MP model. For the AP model simulations, all water and sewer charges (flat and volumetric) are contained in the modeled price structure, so no special winter/nonwinter distinctions are observed.

6.5. Marginal Processing Costs

Modified rate policies affect households differentially, with the potential for some households to increase water use while others decrease theirs. The net result for the overall community may be ambiguous. If the total amount of water processing is modified, there will be effects upon the accounting costs experienced by the water utility. By benchmarking the model IBR against existing rates as in our procedure, we can be reasonably confident that the amount of generated revenue correctly offsets actual costs. All of the cities in this sample have publicly owned, nonprofit utilities and are legally obliged to operate on cost-based principles, without subsidy from tax receipts or higher levels of government. Therefore, historical total revenues can be expected to be well aligned with total costs.

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[8] U.S. Bureau of Labor Statistics CPI-U for January 1995 and January 2011 (http://www.bls.gov/cpi/).

Under these conditions it suffices to have an approximation of marginal processing costs, in order to estimate changes in the utility's operating costs consequent to a rate system switch. Bishop and Weber (1996) report community-specific *short-run* marginal costs for the processing of water in several cooperating U.S. utilities using 3-5 years of monthly information. The data appear to predate our 1995 study period slightly. Results depend importantly on ground water use (pumping costs) and water quality (treatment costs). Exempting cities that buy water, the range of reported marginal processing costs range from 6 cents to 27 cents per thousand gallons. Two Texas cities took part in this study: Houston (27 cents) and San Antonio (9.7 cents). Because these are short-run values and omit wastewater processing, they provide lower estimates for our modeling requirements, especially in light of the capital intensity of water utilities. Previous research has found that these marginal costs may vary considerably on an hourly basis. Feldman, Breese, and Obeiter (1981) tabulate marginal water costs ranging from 9 cents to $1.40 per thousand gallons (1981 dollars) depending on season and hour. Yet, at the monthly level of aggregation appropriate for most rate making, the elevated cost of peak hours is difficult to internalize well.

The available guidance is weak. A marginal processing cost of $1.50 per thousand gallons is assumed for our simulations. Consequently, the marginal price of water under the UR for all MP simulations will be $1.50 plus the marginal sewer rate (four times $1.98 during the winter and zero during the nonwinter) plus the marginal opportunity cost of water. The marginal processing cost of $1.50 is also incurred by the utility as aggregate water use changes. Thus, any decreases/increases in aggregate water use caused by the switch from IBR to UR reduce/enlarge revenue requirements by $1.50 per thousand gallons.

6.6. Opportunity Costs of Water

The four studied cities do not incorporate raw water's opportunity costs in their rates; this predisposition is maintained by the IBR system modeled here. When an IBR system is in use and unprocessed water is sufficiently scarce to possess value, this value is received by consumers in proportion to their consumption. For the UR regime modeled here, opportunity costs are explicitly included in the volumetric water rate.

Information regarding actual marginal opportunity costs (MOCs) can be obtained in a number of ways. There is transactional evidence emergent from water marketing and sometimes the marketing of land when water rights have not been severed from land. Alternatively, various types of economic studies can reveal water value either directly or as a shadow price.

Contemporary transactional information available for Texas includes two active, regionally distinct water markets (Griffin 2011). One of these markets involves surface water, and the other involves an aquifer. Another piece of transactional information emerges from the less common but more momentous purchase of entire irrigation districts by river authorities seeking to enlarge their surface water right holdings so as to accommodate urban growth (Griffin 2011).

Perpetual rights in one Texas surface water market can be obtained for approximately \$2000 per acre foot. In a particular Texas ground water market, perpetual rights are \$6000. The latter figure is equivalent to \$18.41 per thousand gallons. Assuming 15% conveyance losses, 4% discount rate, and an infinite planning horizon for amortizing, an annual value of \$0.866 per thousand gallons is obtained (2011 dollars).[9] A twenty-year planning horizon increases this implied annual value to \$1.59.[10]

Other evidence includes a Texas river authority's purchase of an irrigation district in 1998. For \$75 million, 101,000 acre feet of permanent water rights were conveyed (\$743 per acre foot). Merrill (1997) applied dynamic programming to study a Texas aquifer, finding annual marginal opportunity costs approximating \$1 per thousand gallons. This value includes both marginal user costs and marginal capacity costs.

All of the noted values occur in different basins. Because scarcity conditions are unique in these regions, disparate values are expected. Only one of the four study cities lies in a region

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[9] 6000•0.0030688/0.85=\$21.662/1000gal. \$21.662•0.04=\$0.86648.

[10] \$21.662•(0.04/(1-1.04^(-20)))=1.5939. \$21.662•(0.04/(1-1.04^(-10)))=2.6707.

clearly aligned with one of these values ($6000 per acre foot). Another of the four cities lies in a more eastern part of the state where water scarcity is a much reduced concern.

Given these varied observations, it is prudent to make allowances for alternative MOCs. Therefore, three scenarios of No, Medium, and High scarcity are explored applying respective values of $0, $0.5, and $1 per thousand gallons. It is conceivable that this range of values is not thorough, and no attention to seasonality in these values is pursued here. More extreme values may apply in some circumstances, and there may be omitted opportunity costs deserving of consideration, such as those arising from environmental water or infrastructural scarcities.

7. Results

The simulations are conducted using Mathematica® following the procedure outlined above. In each simulation (MP and AP demand models) each household determines where its demand intersects the appropriate rate representation (MP or AP). This is done for each of the 12 months of the year. All water and sewer fees/rates are incorporated. Meter fees in the MP simulations are deducted from income, thereby causing an income-only effect and shifting demand curves. Meter fees in the AP simulations are embedded in average price (no direct income effect). The only computing idiosyncrasy is to employ an interpolating empirical function to represent the average price function corresponding to R_{ibr}. Otherwise, the AP schedule for an IBR can only be represented as a negatively sloped piecewise (continuous) function, thereby complicating the solution of demand = price. Plots of the actual, piecewise AP function for the block rates of Table 4 with the interpolating function show the approximation to be excellent. Interpolating functions are not used for the AP-UR case or in any MP simulations.

7.1 Welfare Change by Water Use

The three panels of Figure 2 display the perfect information (MP) welfare results for the 1000 households when the IBR is replaced by the UR. Initial (IBR) water use is on the horizontal axis. Panel A is the ample water scenario (MOC = 0). In this case switching to the

UR is weakly beneficial for high and very low water users. For scarce water conditions, shown in panels B and C, higher water users favor the IBR system, and low water users prefer the UR.

The distribution of IBR inframarginal surplus is indicated by Table 5 where the monthly applicable block is identified for the five mid-quintile households. Here, after households are sorted by their annual water use (household 1 being the lowest user), the active block is listed by month for households 100, 300, 500, 700, and 900. As expected, there is seasonality in water use, especially among high-use households who consequently receive layers of inframarginal surplus under the IBR. With a switch to the UR, inframarginal surplus is eliminated and transferred to all households in the form of lower meter fees.

Also apparent in Table 5 is an effect of sewer averaging. During the winter none of these five households consume outside of block 2 because of the high marginal cost of water during this period. Observe that five of the 60 marginal blocks indicated in Table 5 occur exactly at block transitions. This result is enabled by the full-information assumptions of the MP simulation. [Indeed, across all 12,000 simulated consumption months, 1,211 consumption decisions (10%) occur at block transitions.]

Information on the calculated, cost-recovering meter fees is presented in Table 6, and effects of the policy change on the average household are also tabulated. Here, it is seen that rising opportunity costs reduce UR meter fees when opportunity costs are incorporated in volumetric water rates.

With water scarcity, a switch from the IBR to the UR induces (1) reduced water use, (2) reduced water bills, and (3) reduced annual welfare for the average household. Although the latter result may suggest that the average household is not supportive of the policy change, the UR is actually more efficient than the IBR. For example, if the MOC results from marginal user costs associated with depletion, then the future gains (not analyzed here) of the conservation shown in Table 6 will more than offset these one-year losses, producing a present value net gain for the average household.

Figure 3 is the AP counterpart to Figure 2. Whereas the AP simulation of both IBR and UR systems successfully resolves water use and water billing consequences, the AP demand formulation is not satisfactorily indicative of welfare effects. To generate a limited vision of the welfare changes stemming from the AP findings, we assume that

$$\frac{\Delta \mathrm{WTP}_h^{AP}}{\Delta \mathrm{d}_h^{AP}} \simeq \frac{\Delta \mathrm{WTP}_h^{MP}}{\Delta \mathrm{d}_h^{MP}} , \tag{9}$$

where WTP (willingness to pay) is the integral portion of eq. (6). Thus, the numerator of the left-hand side of eq. (9) can be approximated using the denominator simulated by the AP model together with the right-hand side calculated from the MP model. This is a household-specific calculation. That portion of welfare change attributable to modified bills in eq. (6) is calculated directly within the AP simulations.

The patterns of results shown in the panels of Figure 3 are qualitatively similar to the MP findings of Figure 2. Hence, some confidence is generated for the findings of the perfect-information simulation. The only noteworthy distinction is that the AP results exhibit a softer correspondence to water use. This result is anticipated, due to the muted signal recognition occurring with AP (rising volumetric rates coupled with falling meter fees).

7.2 Welfare Change by Income

Results can be organized in a variety of ways. Such opportunities may be advantageous in policy deliberations, such as when questions arise regarding impacts upon households of differing types. An obvious inquiry concerns how the choice of rate system affects different income groups. Figure 4 contains the MP results by income for the three water scarcity levels. A linear trend line is included for the mild and high water scarcity panels.

When water is not scarce, households of various incomes have weak preferences between the two rate systems. This changes as scarcity rises, with greater scarcity causing low-income households to prefer UR. This result opposes the standard opinion that IBRs place greater burdens and responsibilities upon high-income households. We also see in Figure 4 that greater scarcity causes a greater dispersion of welfare consequences. For example, while the trend line of the third panel (MOC=1) indicates that households with annual incomes less than $42000 prefer the UR approach, many of these households prefer IBRs, at least in the short run.[11]

7.3 Welfare Change by Other Factors

For the mild water scarcity scenario and full information model only, the rate system preferences for households of differing numbers of household members, housing value, and outdoor area are displayed in Figure 5. Again, the vertical axes are welfare change for adopting the UR system. Other things equal, smaller households prefer the UR system. This tendency is lessened when considered on a change in welfare per person basis, yet virtually all households of 6 or more people experience loss in a prospective shift to URs. This occurs because larger households consume larger quantities of water.

The middle panel of Figure 5 indicates that households with low-valued properties prefer the UR system whereas owners of high-valued homes are advantaged by the IBR. The final panel of Figure 5 shows a weaker, but similar pattern where households with small outdoor areas favor URs.

8. Conclusions

The inefficiency of IBRs is well known among economists, due to the facts that efficient water prices are equal to marginal-cost prices and marginal cost is insignificantly variable across households during any single period. A second efficiency precept is the ideal of including the social value of water in processed water prices, so that water rate signals are not limited to nonwater resource values for capital, energy, labor, etc.. In this paper we reach beyond questions of allocative efficiency to explore the distributional effects of alternative rate systems.

We find conceptual problems with conventional intuition about the welfare consequences of IBRs as compared to URs. Cost-recovering rate packages modify the customary vision of

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[11] Again, the added water conservation motivated by scarcity-inclusive pricing produces gains for future households when scarcity is the result of depletion. If the scarcity value has been properly computed, the full complement of gains and losses will be broader than the single-year, one-city results emphasized here.

consumer surplus as portrayed by the area beneath demand and above marginal price. What is received by consumers is a combination of both rents and conventional consumer surplus, and this total surplus is distributed among consumers by multiple elements of the rate package. Modifications to volumetric rates can have strong effects on the nonvolumetric fees charged by utilities. The latter can have a dominant welfare impact upon low water users.

Our empirical investigation of IBR versus UR distributional effects on heterogeneous households is supportive of the theoretically suggested insights: if water is sufficiently scarce, high water users (and all household characteristics positively correlated with high water use) are favored by IBRs while low water users prefer scarcity-value-inclusive URs. With the IBR, a substantial portion of surplus and rent is conveyed to high water users, thus causing consumer's net gains to be more positively related to water use. The UR has a greater tendency to apportion net gains across households without regard to their total water use, effectively treating households as more equal shareholders of the utility. In the absence of scarce water, the redistributive consequences of switching between IBRs and URs are greatly weakened, and it is more difficult to identify a distributional preference between rate systems.

In a qualitative sense, all of the obtained empirical results occur for both visions of demand: (1) the perfect information model, where households respond to marginal price exactly and are fully knowledgeable about all aspects of rates and their consumption; and (2) the imperfect-information, average-price model. In the imperfect information case, the relationships discovered between welfare effects and household characteristics are not as pronounced, but they are still present.

Therefore, cities confronting water scarcity have multiple reasons for selecting uniform rate systems that explicitly incorporate water value. Not only are such URs transparent (easy to communicate and understand) and economically efficient, but they also yield distributional consequences that tend to align better with community preferences. URs are found to favor low water users, low income households, low value and low outdoor area properties, and low resident number households. Only the resident-number finding may be unappealing to decision makers, and even this concern is mollified when expressed on a per-person basis.

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Table 1 – Observed household characteristics (n = 957)

	Income	People	Assessed Value	Outdoor Area
Units	$1000/yr	number	$1000	acres
Mean	57.86	2.85	94.75	0.3590
Std. Dev.	34.36	1.32	62.01	1.026
Minimum	15.0	1	4.95	0.0014
Maximum	125.0	8	1166.71	22.263

Table 2 – Two demand models

	MP Model (10711 obs.)		AP Model (10711 obs.)	
	Coef.	*t*	*Coef.*	*t*
ln(d) =				
ln(MP)	-0.5			
ln(AP)			-0.5	
ln(I)	0.15		0.15	
ln(N)	0.291	25.4	0.210	23.5
ln(V)	0.312	35.0	0.179	25.7
ln(A)	0.0247	3.58	0.0391	7.29
ln(C)	0.979	38.4	0.798	40.2
constant	-0.157	-3.33	0.926	25.3

Table 3 – Simulated household characteristics (n = 1000)

	Income	People	Assessed Value	Outdoor Area
Units	$1000/yr	number	$1000	acres
Mean	63.12	2.85	94.39	0.3343
Std. Dev.	31.97	1.32	59.27	0.7443
Minimum	5	1	5.7	0.006
Maximum	161	8	1085.7	16.912

Table 4 – Model IBR system

Water bill = $9.57 + volume charge

Sewer bill = $9.26 + volume charge*

Block (1000 gal.)	Water MP ($/1000 gal.)	Block (1000 gal.)	Sewer MP ($/1000 gal.)
0-2	0	0-2	0
2-10	$1.27	2+	$1.98
10-16	$1.49		
16-42	$1.68		
42+	$1.91		

*Based on December-February average water use.

Table 5 – Applicable block for midquintile households

	Household # (ordered by total water use)				
Month	100	300	500	700	900
Jan	2	2	2	2	2
Feb	2	2	2	2	2
Mar	2	2*	3	3	3
Apr	2	3	3	3	4
May	2	3	3	3	4
June	2	3	3	3*	4
July	2*	3	3	4	4
Aug	2*	3	3	4	4
Sep	2	3	3	3*	4
Oct	2	3	3	3	4
Nov	2	2	3	3	3
Dec	2	2	2	2	2

*Consumption occurs at block endpoint.

Table 6 – Annual effects of IBR to UR switch on the average household (MP simulation)

MOC $/1000 gal	Meter Fee: IBR	Meter Fee: UR	ΔWater Use Amount 1000 gal	ΔWater Use %	ΔBills Amount $	ΔBills %	ΔWelfare $
$0	18.83	14.57	+0.75	+0.57	+1.12	+0.27	-0.93
$0.50	18.83	9.93	-15.75	-11.97	-23.63	-5.72	-6.98
$1	18.83	6.23	-27.08	-20.58	-40.63	-9.84	-17.37

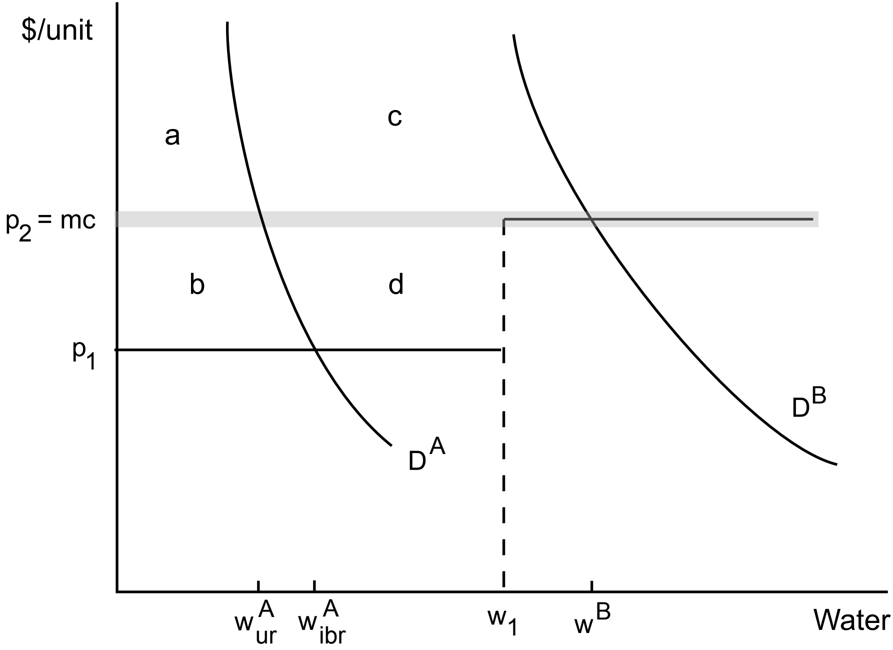
Fig. 1 – Two consumers and two blocks

Fig. 2 – Welfare change (to UR) by initial (IBR) water use, perfectly informed demand

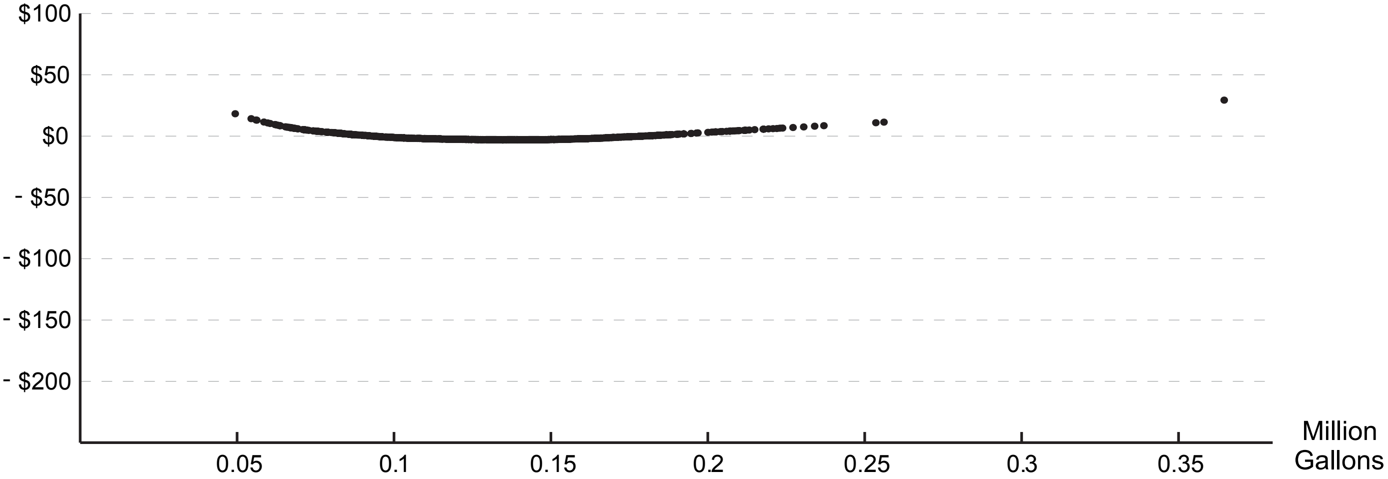
Fig. 3 – Welfare change (to UR) by initial (IBR) water use, imperfectly informed demand

Fig. 4 – Welfare change (to UR) by income

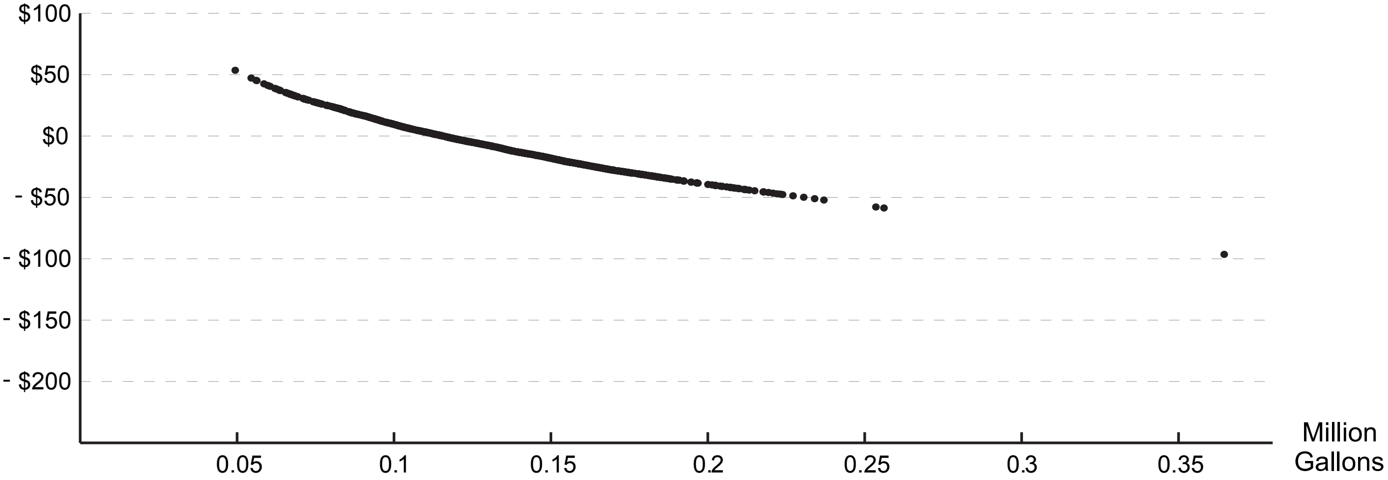
Fig. 5 – Welfare change (to UR) by three household characteristics


$/unit
a
c
p2 = mc
b
d
p1
DA
DB
wAur
wAibr
w1
wB
Water

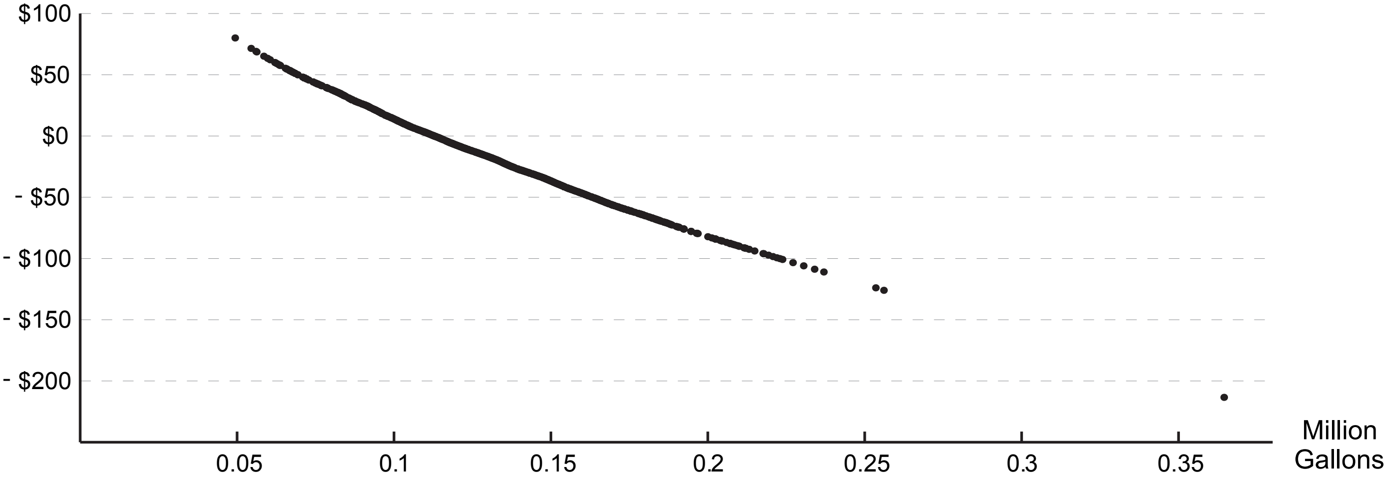
A. Perfect Information Model, MOC=$0

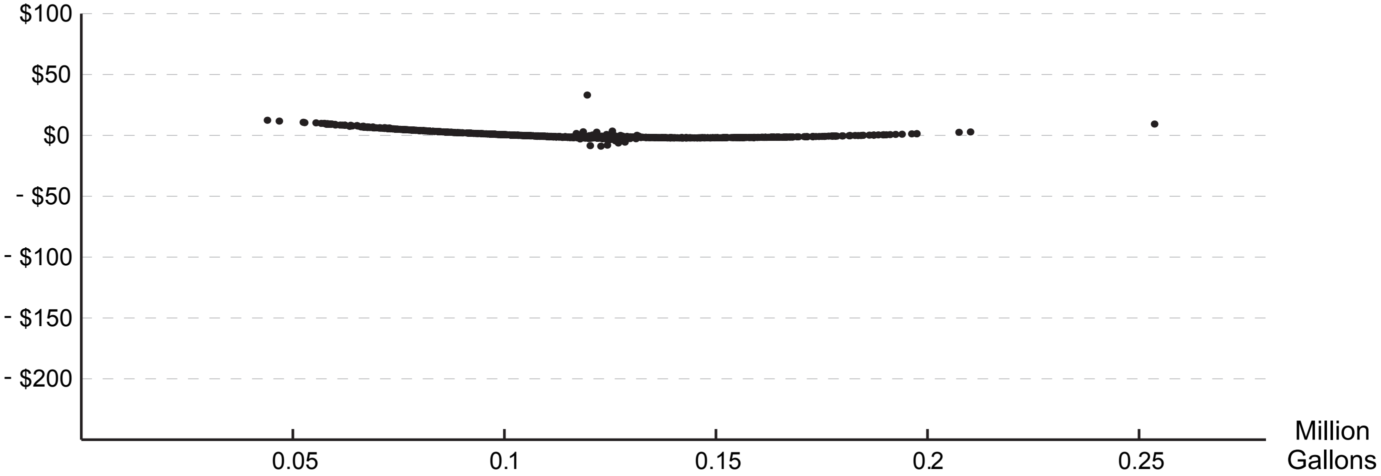


B. Perfect Information Model, MOC=$0.50

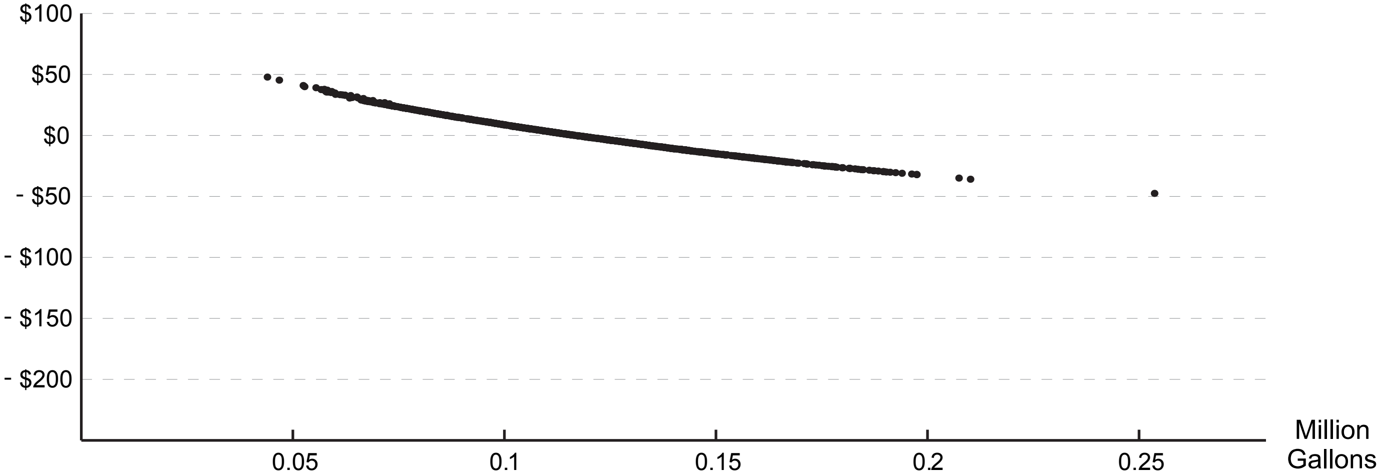


C. Perfect Information Model, MOC=$1

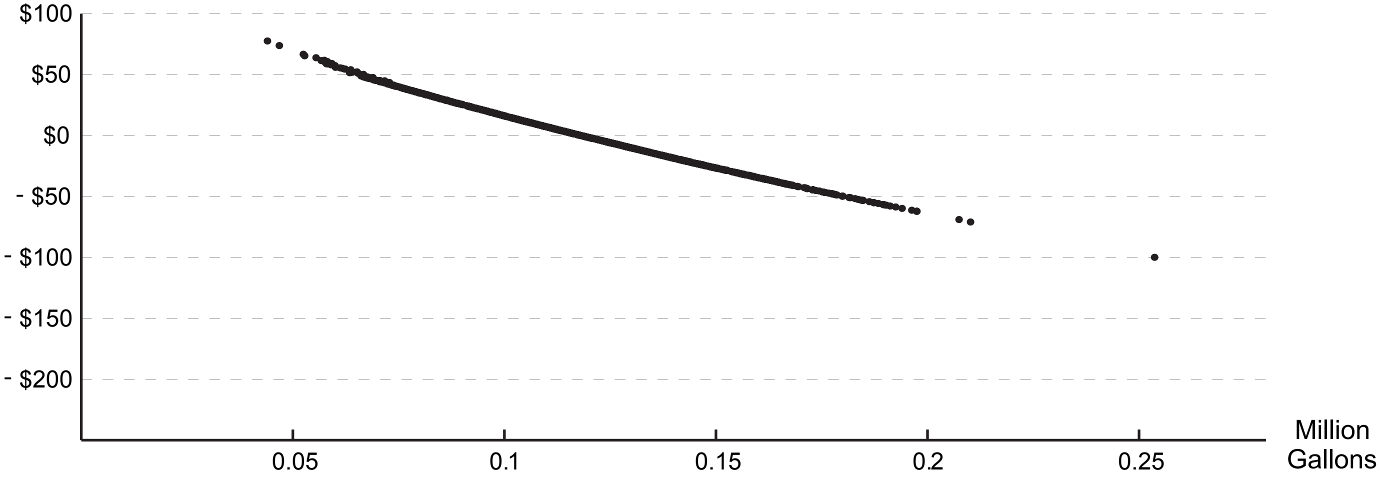




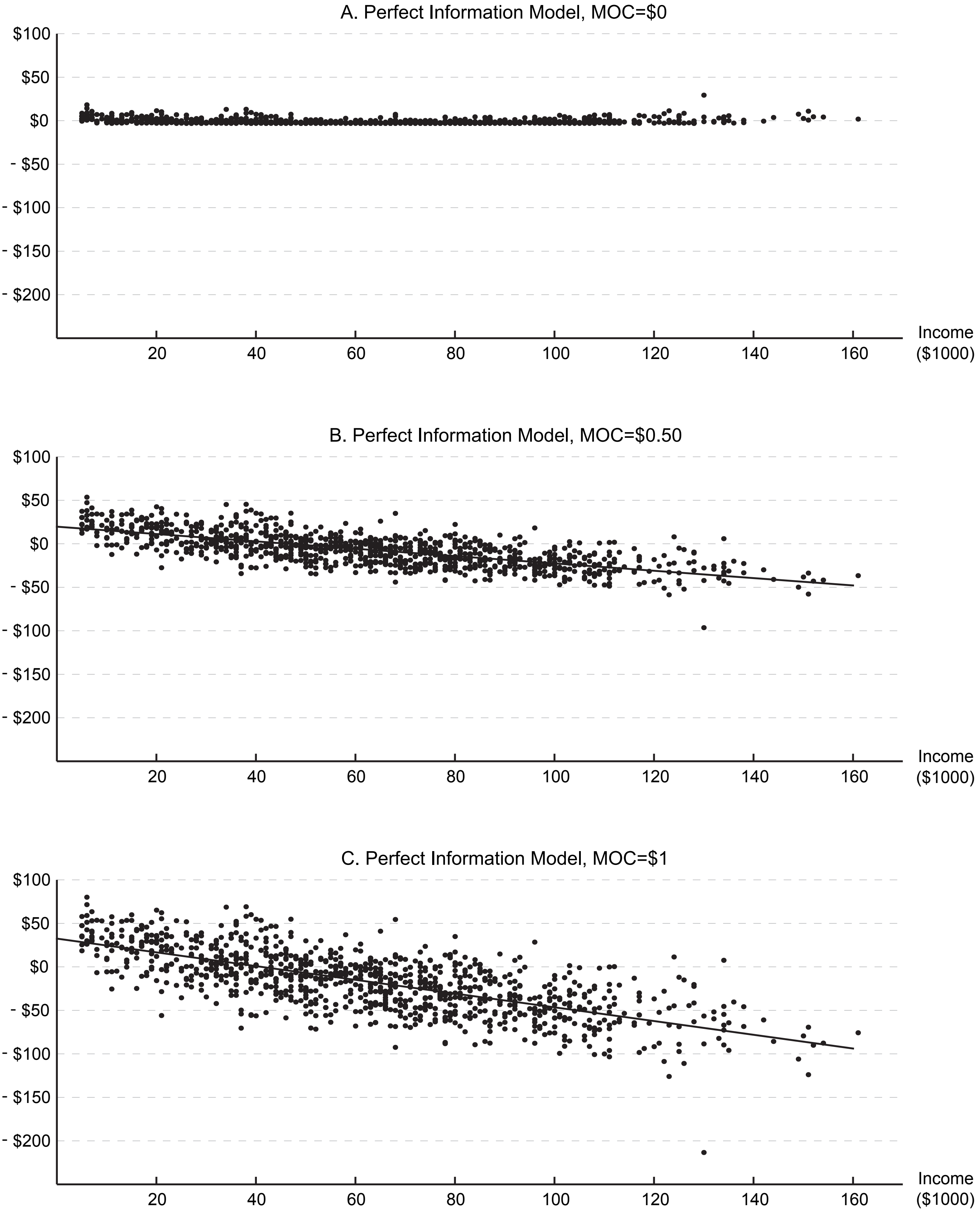
A. Imperfect Information Model, MOC=$0

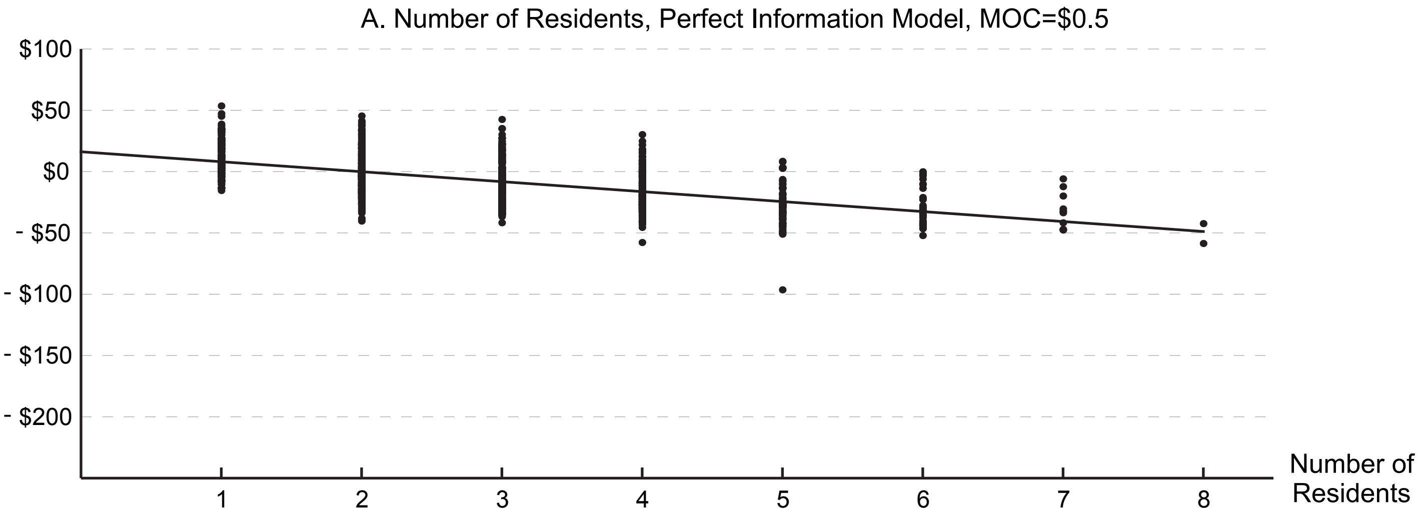


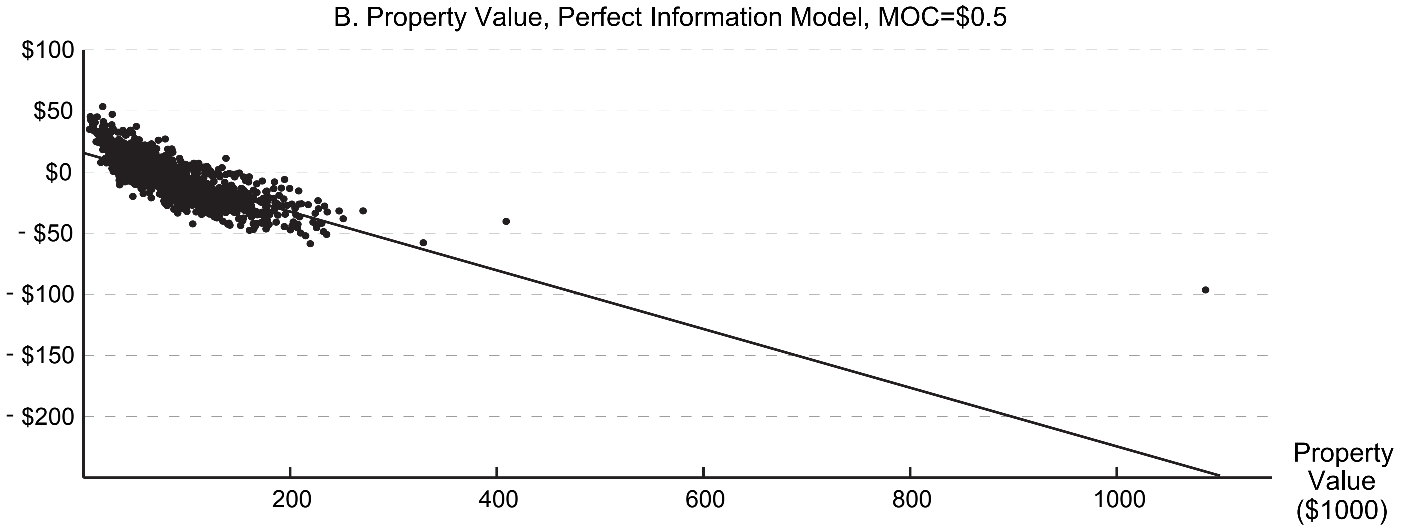
B. Imperfect Information Model, MOC=$0.50

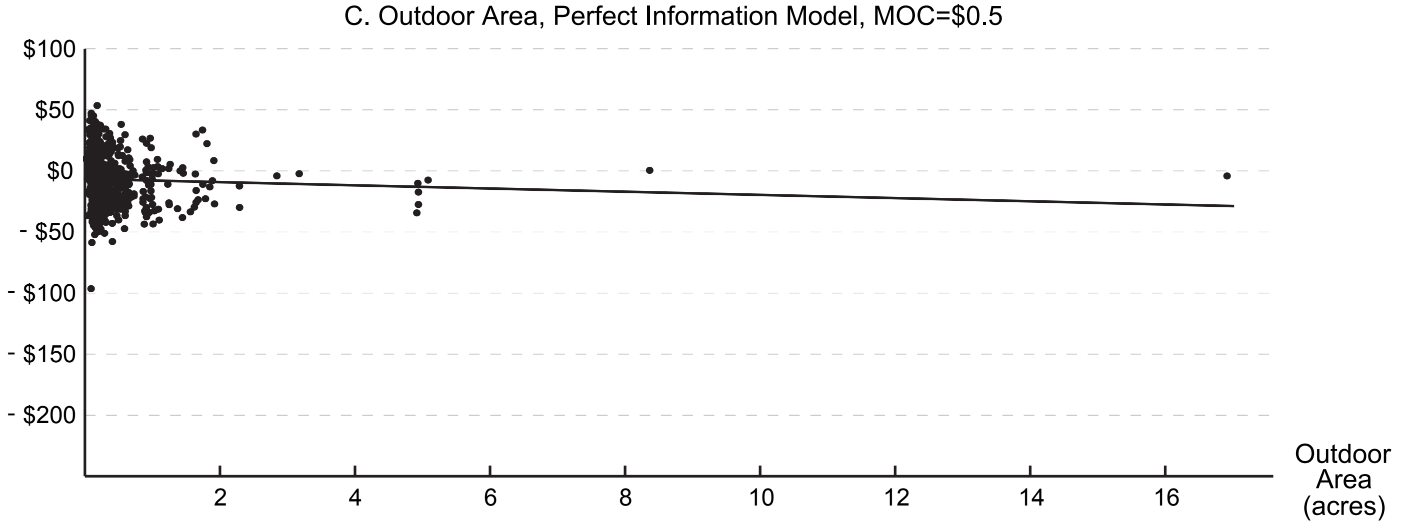


C. Imperfect Information Model, MOC=$1


A. Perfect Information Model, MOC=$0
$100
$50
$0
- $50
- $100
- $150
- $200
20
40
60
80
100
120
140
160
Income ($1000)
B. Perfect Information Model, MOC=$0.50
$100
$50
$0
- $50
- $100
- $150
- $200
20
40
60
80
100
120
140
160
Income ($1000)
C. Perfect Information Model, MOC=$1
$100
$50
$0
- $50
- $100
- $150
- $200
20
40
60
80
100
120
140
160
Income ($1000)


A. Number of Residents, Perfect Information Model, MOC=$0.5


B. Property Value, Perfect Information Model, MOC=$0.5


C. Outdoor Area, Perfect Information Model, MOC=$0.5