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# Can Allocation-Based Water Rates Promote Conservation and Increase Welfare? A California Case Study.

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**Abstract**

An allocation-based rate (ABR) is a special type of increasing block rate (IBR) price structure that is receiving increased attention from urban water suppliers in places like California where population growth and climate change continue to increase water scarcity. Previous work by Baerenklau et al. (2014a, 2014b) investigates the conservation potential of ABR and finds that that consumption under ABR was 10-15% below that of a comparable uniform rate structure for a southern California case study. This paper extends that work by using the discrete-continuous choice framework to estimate household-level welfare effects of ABR for the same dataset. We find that despite the observed decrease in consumption, average household welfare actually increased under ABR due to its nonlinear structure. We also find that similar results would have been achievable with a simpler standard IBR structure. While either of these block rate structures is welfare-preferred to uniform price and quantity instruments, neither clearly dominates the other.

**Keywords**: Discrete-continuous choice model, non-linear pricing, allocation-based rates, increasing block rates, welfare estimation, water demand, water conservation, water scarcity.

# 1. Introduction

Residential water rate structures are often called upon to achieve three very different goals simultaneously. The first is to send an appropriately strong signal to consumers about water scarcity in order to promote efficient use, sustainably manage available supplies, and avoid costs associated with system expansions to meet profligate levels of consumption. This is particularly true in places like California, where anthropogenic warming has substantially increased the likelihood of extreme droughts (Williams, et al., 2015). The second goal is to ensure affordable access to a sufficient amount of water for all households, including those with limited means to pay their water bills. This typically requires a relatively low price, or else a mechanism to cross-subsidize. Moreover it is consistent with the Dublin Statement on Water and Sustainable Development that "it is vital to recognize first the basic right of all human beings to have access to clean water and sanitation at an affordable price" (WMO 1992). Third, water rates are often the main source of revenue for a water supplier, and so the rate structure must provide a reliable revenue stream to recover costs. For many suppliers, this also means maintaining a balanced budget and avoiding excessive profits or deficits over extended periods of time.

It is therefore apparent that water pricing is a complicated management tool that ideally should consider trade-offs between efficiency, equity, and cost recovery (Boland and Whittington 2000). In practice, it is challenging to balance these objectives. In France, Montginoul *et al.* (2015) indicate that doing so is becoming increasingly difficult due to the tightening of environmental regulation, climate change, economic challenges and rising energy prices. Renzetti and Dupont (2015) point out that there is a tendency among

Canadian municipalities to rely on water tariffs primarily for revenue generation, rather than to signal water scarcity. In Spain, Calatrava *et al.* (2015) argue that residential water tariffs fall short on equity concerns, and that water prices should be designed to reflect differences in environmental water stress across regions. In California, there are legal restrictions on cross-subsidization that make equity a more elusive goal.

Historically, many water suppliers have adopted increasing block rates (IBR) because they believe in the potential of this rate structure to address all three concerns. Higher prices in the upper tiers potentially provide a strong signal of water scarcity and thus help bring consumption into balance with limited supply. A lower price in the "basic consumption" tier is potentially beneficial for households that choose to avoid paying higher prices by foregoing less essential consumption (Monteiro and Roseta-Palma 2011). And the existence of multiple tiers enables suppliers to subsidize the low-priced basic consumption tier with revenues earned in the higher priced tiers, thus facilitating fiscal balance. However, it is challenging to design an IBR structure that successfully accomplishes all of these things. Low use customers may never face higher prices even in times of heightened water scarcity. Large (potentially low-income) households may find it difficult to avoid the higher prices in the upper tiers. And the need for cost recovery introduces dependencies between the sizes and prices of the tiers and thus constrains the choice set of the supplier when designing the rate structure (Sibly and Tooth 2014).

More recently, a modified type of IBR called "allocation-based rates" (ABR) has been gaining popularity, especially in California, where the Water Code was modified in 2008 to promote the use of this type of tariff as a way to discourage wasteful or unreasonable use of water.[1,2] ABR is a type of IBR structure in which the block sizes vary according to household-specific characteristics (e.g., number of residents, irrigated area, unusual circumstances such as medical need), environmental conditions (e.g., evapotranspiration), and a judgment by the water utility regarding what constitutes "efficient use" given those characteristics and conditions.[3] This means that price structures can differ across households at any time, and through time for any household. ABR is believed to be an improvement upon IBR for two main reasons. First, by personalizing the rate structure, a similar scarcity signal can be sent to all households. For example, small households are allocated less low-cost water in the basic consumption tier whereas large households are allocated more, thus reducing the distribution of marginal prices paid by all households. This facilitates price-based demand management within a water district, as well as economically efficient use in a broader sense. Second, there is a compelling argument that ABR is also a fair approach to allocating an essential good. Allocations of low-cost water are provided to each household based upon number of residents, and higher prices are charged for less essential uses such as outdoor irrigation. Additional use that is deemed inefficient or wasteful (i.e. above benchmarks determined by the supplier, or in excess of evapotranspiration measurements) is priced at a premium.

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[1] As noted by Dahan and Nisan (2007), this type of tariff has also been implemented in certain areas in Europe such as Belgium, Greece and Spain. However, these are usually less complex, only considering the number of people in the household.

[2] A recent survey of California urban water agencies by the Public Policy Institute of California found that 36% of 173 respondents had adopted allocation-based rates as of June 2016 (Henry McCann, research associate, Public Policy Institute of California, San Francisco, California, personal communication, December 14, 2017).

[3] The definition of "efficiency" used here is engineering rather than economic.

Previous work by Baerenklau et al. (2014a, 2014b) investigates the conservation potential of ABR and finds that that consumption under ABR was 10-15% below that of a comparable uniform rate structure for a southern California case study. This paper extends that work by investigating the household-level welfare effects of this change. Calculating Hicksian welfare measures is complicated by the existence of the non-linear price structure, but we show how the discrete-continuous choice framework can be used to estimate welfare in addition to demand under such a rate structure. We find that despite the observed decrease in consumption, average household welfare actually increased under ABR due to its nonlinear structure. We also find that similar results would have been achievable with a simpler standard IBR structure. While either of these block rate structures is welfare-preferred to uniform price and quantity instruments, examination of the distributions of household welfare effects shows that neither clearly dominates the other.

## 2. Demand and welfare estimation under non-linear pricing

The two-error discrete-continuous choice (DCC) model has become a popular approach for estimating demand under non-linear pricing because it is theoretically consistent and effectively addresses the inherent price endogeneity that arises in empirical work. Welfare analysis under non-linear pricing has remained less common. A few studies such as Renzetti (1992), Renzetti (1999), García and Reynaud (2004), and Porcher (2014) propose alternative linear water tariffs and then analyze welfare effects associated with each tariff. However, estimating the welfare effects of non-linear pricing is challenging because, as noted by Bockstael and McConnell (1983), a closed-form expression for the Marshallian demand function generally does not exist when the budget constraint is nonlinear. As a consequence, a closed-form expression for the indirect utility function cannot be derived by plugging the Marshallian demand function into the direct utility function, thus closed-form expressions for Hicksian welfare measures also cannot be derived. A possible solution to this problem was suggested by Strong and Smith (2010), who note that recovery of the parameters of the direct utility function would permit welfare analysis that could handle both marginal and non-marginal changes in price. The present analysis builds on this suggestion and uses the DCC modeling framework to estimate welfare effects under multiple non-linear and linear pricing structures.

Originally developed by Burtless and Hausman (1978) for labor supply, the DCC approach has been surveyed and reviewed by Moffitt (1986, 1990) and adapted by Hewitt and Hanemann (1995, 2000) and Pint (1999) for applications to water demand.[4] Waldman (2000, 2005) and Hewitt (2000) generalized the associated likelihood function that Olmstead et al. (2007), Olmstead (2009) and Baerenklau et al. (2014a, 2014b) used in recent investigations of IBR water pricing. The two-error DCC model was developed specifically to deal with the problematic nature of nonlinear (especially block rate) prices that can confound attempts to estimate how quantities respond to changes in such prices. The problem in a standard single-error regression model with nonlinear prices is that the observed price is endogenous because it depends on the observed consumption level, which depends on the error term. Thus, in such a model, the error term, observed

[4] The purpose of this section is not to provide a complete overview of the DCC model, but rather to present the salient features for this analysis. For a more thorough overview, the reader is referred to Burtless and Hausman (1978) and Hewitt and Hanemann (1995).

consumption level, and observed price are all correlated. This tends to bias the coefficients derived from a regression of quantity on price.

The DCC model breaks the correlation between the price and error terms by breaking up the consumption decision into two sequential steps. The first step is the selection of the optimal consumption block and the second step is the selection of the optimal consumption level within that block.[5] The benefit of this approach is that conditioning the second choice on the first allows the price to enter the analysis as a constant. To implement this approach, it is typically assumed that a single function $x(p, d)$ exists that approximates household demand in any block by plugging in the block-specific values of price $p$ and virtual income $d$ (Hewitt and Hanemann 1995).[6] A preference heterogeneity term $\varepsilon$ is assumed to enter additively, such that a household's optimal choice is given by $x(p, d) + \varepsilon$. A consumption shock $\eta$ also is assumed to enter additively, such that the observed choice is given by $x(p, d) + \varepsilon + \eta$.

With this specification in mind, consider a graphical depiction of the consumer's decision in figure 1. The figure shows an indifference curve and a budget constraint under an IBR structure. The blocks are denoted by $j \in \{1, \dots, J\}$, the block boundaries (kink points) by $k_j, j \in \{1, \dots, J + 1\}$, m is household income (assuming no fixed fees), and d is the virtual income associated with interior block 2, which is defined as: $d = m + (p_2 - p_1)k_1$ . By construction, a household chooses to consume in block j when its optimal choice $x(p_j, d_j) +$

[5] The model also incorporates optimal consumption between blocks at a kink point. For purposes of exposition, and without loss of generality, we disregard these corner solutions for now.

[6] Virtual income refers to actual income adjusted by the difference variable (Nordin, 1976). This variable measures the difference between the cost households would have paid if all units had been charged at the marginal price and the actual water cost.

ε is greater than $k_j$ and less than $k_{j+1}$ , or: $k_j - x(p_j, d_j) < \varepsilon \le k_{j+1} - x(p_j, d_j)$. Similarly, a household chooses to consume at kink point j when its optimal choice $x(p_{j-1}, d_{j-1}) + \varepsilon$ is greater than $k_j$ and its optimal choice $x(p_j, d_j) + \varepsilon$ is less than $k_j$, or: $k_j - x(p_{j-1}, d_{j-1}) < \varepsilon \le k_j - x(p_j, d_j)$. Given these optimal choices of block and kink points, and assuming independent normal distributions for the error terms, observed consumption can be expressed as (Hewitt 2000):

$$x = \begin{cases} k_1 + \eta, & -\infty < \varepsilon \le k_1 - x(p_1, d_1) \\ x(p_1, d_1) + \varepsilon + \eta, & k_1 - x(p_1, d_1) < \varepsilon \le k_2 - x(p_1, d_1) \\ k_2 + \eta, & k_2 - x(p_1, d_1) < \varepsilon \le k_2 - x(p_2, d_2) \\ x(p_2, d_2) + \varepsilon + \eta, & k_2 - x(p_2, d_2) < \varepsilon \le k_3 - x(p_2, d_2) \\ k_3 + \eta, & k_3 - x(p_2, d_2) < \varepsilon \le k_3 - x(p_3, d_3) \\ \vdots & \vdots \\ x(p_J, d_J) + \varepsilon + \eta, & k_J - x(p_J, d_J) < \varepsilon \le k_{J+1} - x(p_J, d_J) \\ k_{J+1} + \eta, & k_{J+1} - x(p_J, d_J) < \varepsilon < \infty \end{cases} \quad (1)$$

The associated likelihood function can be derived as in Waldman (2000, 2005) and Hewitt (2000), and a standard constrained optimization routine can then be used to find the maximum likelihood coefficient estimates associated with the price and income variables and other regressors in the demand function.

As noted earlier, welfare analysis is challenging under non-linear pricing because a closed-form expression for the Marshallian demand function generally does not exist. This issue can be seen graphically in figure 2. Suppose that the original nonlinear budget is represented by the solid black line segments and a consumer optimally selects to consume on the interior of the second segment, i.e. within block 2. This optimal consumption is given by the tangency point of the indifference curve and the dashed black line. Now assume that the price of block 2 changes from $p_2$ to $p'_2$. The budget set is now denoted by the solid grey line segments in figure 2. If a Marshallian demand function $x(p, d)$ exists that describes optimal consumption conditional on selecting this block, it would be possible to derive optimal water consumption under the new price by holding virtual income constant and changing price accordingly. In this case, the tangency between the dashed grey line and the indifference curve would indicate this optimal level. However, doing this would violate the new budget constraint because the change in price generates a simultaneous change in virtual income to d´ which must be accounted for. Thus, the consumption predicted by $x(p, d)$ while holding virtual income constant is not optimal, and thus $x(p, d)$ is not the Marshallian demand.

One possible solution to this problem of accurately predicting the consumption response to a price change under block rates is to maintain the closed-form expression $x(p, d)$ and to adjust virtual income accordingly rather than hold it fixed. However, this solution only works for small price changes (such as depicted in figure 2) that do not cause consumers to move from one facet of the budget set to a kink point or to another facet. For large price changes, this approach will yield incorrect results. As Bockstael and McConnell (1983) point out, accurately predicting the consumption response to large price changes requires a model that includes not only the local conditions faced by the consumer (i.e. block price and virtual income), but also the global properties of the budget constraint (i.e. prices in other blocks and locations of kink points).

The upshot of this is that demand must be expressed as the implicit solution to the full set of Kuhn-Tucker conditions describing utility maximization subject to multiple constraints (i.e. budget facets) rather than expressing it in closed form. This has important implications for welfare analysis. Foremost, it means that a closed-form expression for the indirect utility function cannot be derived by substituting $x(p, d)$ into the direct utility function, which in turn means we cannot rely on closed-form expressions for Hicksian (or Marshallian) welfare measures. Instead, as suggested by Strong and Smith (2010), the analyst must utilize an empirical framework that recovers the direct utility function, as knowledge of this function would enable assessment of non-marginal changes in price structures.

An appealing empirical structure is the semi-log demand framework for which the direct utility function is known and for which demand satisfies non-negativity.[7] The semi-log Marshallian demand is:

$$x^*(p, d) = \exp(\alpha + \beta p + \gamma d) \tag{2}$$

where x is water consumption, p is water price, d is virtual income, and $\{\alpha, \beta, \gamma\}$ is a set of estimable parameters. Note that $\alpha$ can be the scalar product of vectors of parameters and regressors. The estimated demand function contains all of the information needed to recover the direct utility and expenditure functions, which are known (Bockstael et al. 1989).[8] The utility function is:

$$u(x) = \frac{\beta+\gamma x}{-\gamma\beta} \exp\left[\frac{\gamma\left(\alpha x-\beta\left(d-c(x)\right)-x\ln x\right)}{\beta+\gamma x}\right], \tag{3}$$

where c(x) is the cost of consuming x, and the second good in the equation is assumed to be the numeraire and thus has been replaced by (d − c(x)). The expenditure function:

[7] The Cobb-Douglas utility function produces demand equations that are linear in the logs of income and price, but the associated coefficients must be 1 and -1, respectively. The linear demand system also is undesirable because additional effort is needed to address the non-negativity of demand (e.g. modeling as a tobit).

[8] The direct utility function shown here differs slightly from Bockstael et al. (1989) which contains a typo.

$$e(p, u(x)) = -\frac{1}{\gamma}\ln\left[-\gamma u(x) - \frac{\gamma}{\beta}\exp(\alpha + \beta p)\right]. \tag{4}$$

Reconciling this theoretical framework with the DCC model requires both a conceptual change and the addition of the two error terms. First, the conceptual change affects how $x^*(p, d)$ is interpreted in the DCC model. Rather than as the Marshallian demand function, $x^*(p, d)$ should be interpreted simply as the tangency condition for optimal consumption conditional on the choice to consume in a particular block. Therefore, consumption cannot be predicted using this estimated conditional demand function alone. Rather, the analyst must substitute $x^*(p, d)$ into equation (1) and numerically integrate over the distributions for $\varepsilon$ and $\eta$. Moreover, additional properties normally attached to this function (when appropriate to interpret as the Marshallian demand function) do not apply—as in Strong and Smith (2010), $x^*(p, d)$ is considered to be an estimating equation but nothing more.

To append the error terms, first take the log of $x^*$ and redefine this expression using notation from the DCC framework: $x(p, d) \equiv \ln(x^*(p, d))$. Thus a household's observed consumption is given by $x(p, d) + \varepsilon + \eta$. Next, recall that $\varepsilon$ represents preference heterogeneity and is thus a component of the utility function, whereas $\eta$ is an ex post consumption shock that affects utility only through x. It is therefore convenient to redefine $\alpha \equiv \alpha + \varepsilon$ when working with the direct utility function.

Maximum likelihood estimation using the DCC framework produces point estimates for $\{\alpha, \beta, \gamma, \sigma_\varepsilon, \sigma_\eta\}$, where $\sigma_\varepsilon$ and $\sigma_\eta$ are the standard deviations for the error terms. As noted above, the analyst must numerically integrate over the distributions of these error terms to estimate unconditional demand. This is straightforward but requires original coding in a programming language such as Gauss, R, or Matlab to address the piecewise nature of the conditional expressions in equation (1). For the present study we use Gauss-Hermite quadrature, but other numerical integration techniques could be used.

Importantly, a structurally identical numerical integration is required to estimate the expected utility and, with a designated reference price level, the expected expenditures associated with predicted consumption levels. Holding this reference price fixed also permits calculation of expected Hicksian welfare measures associated with potentially non-marginal changes in features of the block price structure, including entirely different price policies (e.g. uniform pricing) or non-price policies (e.g. quantity restrictions), which is the ultimate goal of our analysis. Here we compute Equivalent Variation (EV) measures, as these are usually preferred over Compensating Variation (CV) when used to rank alternative price policies (Chipman and Moore, 1980; Mas-Colell et al.,1995). Chipman and Moore (1980) showed that CV adequately compares alternative pricing policies in the case of homothetic preferences and changes in price but not in income. However, as discussed by Ruijs (2009), a change in price also generates changes in virtual income when analyzing the effects of alternative IBR tariffs.

# 3. Empirical application

## 3.1. Eastern Municipal Water District

As an empirical example, we use a household-level panel dataset from the Eastern Municipal Water District (EMWD) in southern California for the period 2003-2012.[9] The

[9] The dataset for this study is the same as that used in Baerenklau et al. (2014a)

data are drawn from residential account records maintained by EMWD, one of the 26 member agencies of Metropolitan Water District of Southern California, a major regional water wholesaler. EMWD serves an area of western Riverside County, comprising around 795,000 people over 555 square-miles. Cities served in the EMWD service area include Hemet, Menifee, Murrieta, Perris, San Jacinto and Temecula—most of which are below the California median household income (U.S. Bureau of the Census 2015).

During the period of analysis, California experienced a 3-year drought from 2007 to 2009. As a response, Metropolitan directed its member agencies to reduce water consumption by 20%. EMWD responded by changing its water price structure in April 2009 from a uniform rate per unit of water consumed to an allocation-based rate (ABR) to encourage water conservation. EMWD adopted a four-block ABR structure, with a household's cumulative block sizes calculated as follows:

Block 1: $\mathrm{w}_1 = (\mathrm{HHS} \times \mathrm{PPA}) \times \mathrm{DF} + \mathrm{IV}$

Block 2: $\mathrm{w}_2 = \mathrm{w}_1 + (\mathrm{ET} \times \mathrm{CF} \times \mathrm{IA} + \mathrm{OV}) \times \mathrm{DF}$

Block 3: $\mathrm{w}_3 = 1.5 \times \mathrm{w}_2$

Block 4: Water use in excess of $\mathrm{w}_3$

Variables used here are household size (HHS), per-person allowance (PPA), drought factor (DF), indoor variance (IV), evapotranspiration (ET), conservation factor (CF), irrigated area (IA), and outdoor variance (OV). HHS is self-reported by each household; PPA was set at 60 gallons per person per day, in line with California water efficiency standards at the time; DF can range between 0 and 1, but was set equal to 1 during the period of analysis; IV is negotiated between EMWD and households that report unusual indoor circumstances such as medical need or in-home daycare; ET is derived from real-time measurements for a reference crop which are then adapted to 50 microclimate zones within the EMWD service area; CF is a constant that converts the reference crop ET to turf grass ET; IA is approximated from county assessor data before customers are invited to submit adjustment requests; and OV is negotiated between EMWD and households that report unusual outdoor circumstances such as maintenance of large animals or turf grass establishment. Block 1 is intended to cover efficient indoor use and block 2 is intended to cover efficient outdoor use. A household's "water budget" is defined as the sum of the first two blocks, or cumulative consumption of $w_2$. Consumption above $w_2$ is deemed inefficient and is thus charged a significantly higher price than consumption below $w_2$. Most of the variability in water budgets across households comes from heterogeneity in HHS (ranging from 1 to 18 residents) and IA (ranging from 0 to 172,000 square feet). IV and OV are highly unusual, applying to less than 3% of households.

Figure 3 shows a comparison of the price paid per unit of water before and after the rate change. The solid black horizontal line shows the original uniform rate, and the solid grey "staircase" shows the allocation-based rate. The vertical dashed line shows the water budget, at the end of the second block. The price paid under the uniform rate was higher than the price associated with the first block of the ABR structure, but slightly lower than the price associated with the second block. That is, the ABR structure improved the affordability of water for basic indoor needs compared to the uniform rate structure. Also, the difference between the uniform price and the prices associated with the third and the fourth blocks of the ABR structure is substantial—evidence of a stronger conservation signal to consumers. Overall, the change in the rate structure substantially modified the price per unit of water. Consumption also changed substantially: Baerenklau et al. (2014a) estimate that by 2012, household consumption under ABR was around 17% below where it was just prior to the rate change. As a consequence of these significant changes in prices and consumption, the rate change may also have had a noticeable effect on consumer welfare. The magnitude of this welfare effect, and the question of whether a different water conservation strategy could have been more economically efficient, are the main questions addressed by the present analysis.

## 3.2. Data

Our data is comprised of 13,565 single-family residential accounts with uninterrupted monthly water use records between January 2003 and September 2012. The fact that these accounts remained open is a good indication that there were no tenancy changes in these households during this period.[10] In addition to monthly water consumption data, EMWD also provided information on prices paid by each account, the household size (HHS) and irrigated area (IA) associated with each account, dates when households were asked to voluntarily reduce water consumption, monthly ET under allocation-based rates for each of the 50 microclimates, and the relevant microclimate for each account.[11] EMWD also provided the latitude and longitude of each account, which enables geo-referencing to

[10] An exception could be rental properties for which the utility accounts are registered to the owner rather than the tenants. Unfortunately, it is not possible to identify such accounts in this dataset.

[11] Monthly ET under uniform rates was estimated by Baerenklau et al. (2014a) using data from the California Irrigation Management Information System (CIMIS).

obtain demographic information at the census tract level.[12] Summary statistics for the full dataset are presented in Table 1. Conservation requests refer to the fraction of months in which households were asked to increase water conservation efforts, typically due to system maintenance or heat waves.[13] Nominal and real prices are the prices charged per hundred cubic feet (CCF) of water (one uniform rate from 2003-08; four increasing block rates from 2009-12). Under uniform-rate pricing, the price charged is the same as the average price paid by households. However under allocation-based rates, the average price paid is a function of water consumed and thus is listed separately in the table. As in Strong and Smith (2010), money budgets are based on census income (Minnesota Population Center 2011) and are adjusted for the fraction of income typically spent on the category of "utilities, fuels, and public services" (U.S. Bureau of the Census 2012).[14] Money budgets also are adjusted for temporal changes in per-capita personal income for the Ontario-Riverside-San Bernardino metropolitan statistical area (U.S. Bureau of Labor Statistics 2013). Education is expressed as the fraction of the census tract reporting "some college" or more education (U.S. Bureau of the Census 2012). Household size, irrigated area, and education are treated as constant characteristics because we lack information on temporal changes in these variables.[15]

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[12] Our sample covers 88 census blocks. The number of households per block ranges from 1 to 562 with a median of 141.

[13] EMWD also had mandatory water use restrictions in place during the observation period. These included no hosing down hard surfaces, no irrigation runoff, required use of automatic shut-off nozzles when washing vehicles, etc. However these mandatory restrictions did not vary during the study window.

[14] Using data from the 2010 Consumer Expenditure Survey, Baerenklau et al. (2014a) estimate the following relationship between budget $(y)$ and income $(m)$ for the sample: $y = 99.8941m^{0.3339}$, $R^2 = 0.9915$. Any applicable fixed fees are deducted from this budget prior to demand estimation.

[15] Census data suggests that overall education levels in the study area remained fairly constant from 2000-2010.

## 3.3. Parameter Estimation

Similar to Baerenklau et al. (2014a), we estimate water demand in a DCC framework using maximum likelihood techniques to derive estimates of $\{\alpha, \beta, \gamma, \sigma_\varepsilon, \sigma_\eta\}$.[16] Specifically, we substitute equation 2 into equation 1 with all regressors entering $\alpha$ linearly. A notable difference with Baerenklau et al. (2014a) is that we account for persistent unobserved household preference heterogeneity in the DCC model. To do this, we first estimate a demand model under uniform pricing for the period 2003-08 using OLS. We then use this model to compute a mean prediction error for each household to capture this persistent unobserved heterogeneity. Finally we include these mean prediction errors as a regressor in the DCC model which is estimated for the same set of households under ABR pricing for the period 2009-12.[17,18] We do this because, although the standard DCC model incorporates a random "preference heterogeneity" term (here, $\varepsilon$), this term is assumed to be independently distributed across choice occasions. Thus, the standard model does not account for persistent unobserved differences across individuals, which potentially biases the parameter estimates. Our two-step approach effectively introduces a household-

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[16] A critique of the DCC framework is that nonlinear pricing is too complex for consumers to understand, and therefore such a structural model is inappropriate. In this particular case, EMWD undertook a major information and education campaign prior to the implementation of ABR. The district used public meetings, email, and billing inserts to educate customers about the rate change; placed easily understood information about allocation-based rates on its website; ensured that customer bills showed disaggregated charges by block; and used its website to help customers read and understand their bills. All of this lends additional confidence to the use of a structural modeling framework.

[17] This is similar to the control function method described by Woolridge (2015).

[18] This preference heterogeneity term also could subsume unobserved commitments to fixed water-consuming capital goods that differ across households (as considered in Strong and Smith 2010). For most customers, the largest such commitments are likely to be landscaping and pools. Because our data is from an allocation-based rate schedule, we have information about these outdoor commitments at the household level. Therefore we are confident that this new term is mostly capturing preference heterogeneity, but it also will include other commitments to smaller fixed goods.

specific constant term (analogous to a fixed effect), thus helping to control for these differences.

Parameter estimates and robust standard errors for the DCC model are shown in table 2. The estimation results are generally very good. Signs are intuitive and significance levels are high (due in part to the large number of observations). Demand is positively correlated with education level, household-size, irrigated area, and evapotranspiration. Demand is negatively correlated with conservation requests.[19] There also appears to be a small negative time trend. As noted earlier, California experienced a drought during the period of analysis, which may have led to changing attitudes about water conservation, increasing adoption of water conserving devices, or other changes that are unobserved in our data but captured by this trend. Price is negatively correlated, as expected. While DCC models tend to estimate higher price elasticity values compared to other demand models, in our case the estimated price elasticity is -0.38, which is very close to the mean of -0.365 reported in the meta-analysis by Sebri (2014). Income is positively correlated, and the estimated income elasticity is 0.42 when measured with respect to the monthly money budget. The relative magnitudes of the seasonal dummies also are intuitive, which is an improvement upon Baerenklau et al. (2014a) and suggests that persistent preference heterogeneity is an important feature of the data. Figure 4 shows that the model exhibits relatively good fitness.

## 3.4. Welfare Analysis

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[19] We do not include individual conservation rebate programs as regressors due to small numbers of observations. The aggregate savings from such programs accounted for less than 0.5% of total residential deliveries during the period of analysis (Baerenklau et al. 2014a).

Given the model estimates and the evidence in figure 4 that the numerical integration routine produces reasonably good predictions for consumption, we turn to the question of what other policies EMWD might have pursued if they had not adopted an ABR structure. As noted in the introduction, water rate structures often aim to achieve three objectives: balancing supply and demand, mitigating customer impact, and revenue generation. As in Sibly and Tooth (2014), we approach this problem of tariff selection by assuming the water district ideally desires to make its customers as well-off as possible given targeted levels of aggregate water consumption and revenue generation. For the present case, we assume the observed levels of consumption and revenue under the ABR structure are good approximations of EMWD's target levels, and thus we hold these fixed. We then consider other rate structures that achieve the same target levels of consumption and revenue, and we examine the customer welfare outcomes under those rates compared to welfare under ABR. To make these comparisons we focus on the last 12 months of our data (October 2011 to September 2012) during which time the initial reduction in consumption due to the rate change had stabilized. Thus our comparisons provide an estimate of the longer-term customer welfare effects of alternative approaches to achieving desired levels of water consumption while also maintaining a balanced budget.

To establish a common baseline from which to compare the welfare effects (equivalent variation) of alternative rate structures, we use the estimates in table 2 to derive expected consumption levels, utilities, and expenditures during 2011-12 under the hypothetical case that the 2008 uniform price policy had remained unchanged. We then consider five approaches to achieving the levels of consumption and revenues that were generated by the ABR structure, and measure the welfare effects of each of them against this baseline.[20] The five alternative rate structures are:

- Tariff 1: EMWD's allocation-based rates.
- Tariff 2: A standard IBR structure that is similar to Tariff 1: block sizes are set equal to the average block sizes in Tariff 1, relative prices (across blocks) are set equal to those in Tariff 1, and both price levels and the fixed charge are adjusted to achieve the targeted consumption and revenue levels.
- Tariff 3: A uniform rate where the marginal price is raised above the 2008 level and the fixed charge is reduced in order to meet the targeted levels of water consumption and revenue.
- Tariff 4: The 2008 EMWD uniform rate, but with a proportional quantity restriction (similar to what is accomplished under an irrigation restriction) and an increase in the fixed charge to compensate for the revenue shortfall.
- Tariff 5: A "pro-environment" ABR structure that reduces the indoor allowance from 60 to 26.4 gallons (100 liters) per person per day (Howard and Bartram, 2003), thus reducing the sizes of blocks 1 and 3. As with Tariff 2, relative prices (across blocks) are set equal to those in Tariff 1, and both price levels and the fixed charge are adjusted accordingly.

Table 3 shows the charges associated with these rate structures. In addition to the descriptions above, we note that the block prices under Tariffs 2 and 5 are lower than under Tariff 1, but the fixed charges are higher to compensate for the lost revenue from water

[20] Recall that demand had declined by about 17% under ABR as of 2012.

sales. The uniform price under Tariff 3 is higher than the first two block prices under all three of the block rate tariffs, and also higher than the uniform price under Tariff 4. That is, Tariff 3 charges the highest price for lower levels of water consumption, which tend to be devoted to more essential uses. However, the fixed charge under Tariff 3, which is charged regardless of the level of water use, is much lower than the other fixed charges.

Table 3 also shows the average annual proportions of households per block under the three block rate tariffs. The majority of households fall into the second block under all three tariffs, but the proportion of households in this block is substantially larger under Tariff 5 than Tariff 2, and under Tariff 2 than Tariff 1. Conversely, the proportion of households in the first block is substantially smaller under Tariff 5 than Tariff 2, and under Tariff 2 than Tariff 1.

The results of the welfare analysis are reported in table 4, which shows descriptive statistics for the customer-level equivalent variation (EV) under each of the four rate structures. We observe that each of the three block rate structures generates a slight *improvement* in terms of average welfare, despite achieving the targeted 17% reduction in consumption. The other two rate structures show the more intuitive decrease in average welfare that we expect when prices rise and consumption falls. The customer welfare improvements under the block rate structures are possible because in each case the block 1 price is below the baseline uniform price, and thus the new budget set protrudes beyond the old budget set at these lower levels of consumption, thus enabling these consumers to achieve higher levels of utility. Table 4 shows that 62% of households benefit under Tariff 1, 66% benefit under Tariff 2, and 54% benefit under Tariff 5. At higher prices the new budget set does not extend as far as the old budget set, and so these other consumers suffer welfare losses. On average, there is a net gain.

The reader may wonder how these results can be squared with the standard theoretical result of the optimality of uniform pricing. The answer is that we are not working within the standard framework. Rather we have introduced additional constraints (on aggregate consumption and revenues) that move our problem out of the standard framework and imply that solutions are second-best optimal. Baumol and Bradford (1970) point this out for the case of a profit constraint in a general equilibrium context. Leland and Meyer (1976) show through numerical simulation that block pricing can improve welfare when a profit constraint binds. Goldman, Leland and Sibley (1984) provide an algebraic derivation and proof of the optimality of nonlinear pricing for a simple analytical model, again with a binding profit constraint, and highlight the role of income effects in determining a second-best optimal price schedule. Thus the results of the present analysis are actually consistent with applicable theory.

Returning to the results, table 4 also shows that the block rate structures produce greater variability in household-level impacts, with larger minimum and maximum welfare effects compared to the other policies. Among the three block rate structures, Tariff 2 achieves the largest average welfare improvement and makes the largest number of households better-off, but also has the largest minimum (and maximum) welfare effect. Tariff 5 achieves the smallest average welfare improvement, makes the smallest number of households better-off, but has a more moderate minimum (and maximum) welfare effect. Tariff 5 appears to be dominated by Tariff 1 in terms of the reported welfare statistics, but tradeoffs exist between Tariffs 1 and 2: fixed blocks achieve slightly higher welfare on average and can make slightly more households better-off, but households that are negatively affected can fare significantly worse under fixed blocks than under EMWD's allocation-based rates. Two competing effects drive this outcome. First, under our fixed block tariff, prices must be lowered relative to allocation-based rates to achieve the targeted level of consumption; second, the fixed charge must be increased to cover the associated revenue shortfall. Evidently the first of these dominates the second in our case, leading to higher average welfare.

Table 5 shows the mean welfare effects by income and baseline water use terciles. The numbers in parentheses express these effects as percentages of the monthly money budget. All of the policies appear to be somewhat regressive, with relatively better welfare implications for wealthier (3$^{rd}$ tercile) households. However, the three block rate structures are clearly preferred over the other two policies, regardless of income level. Among the block-rate policies, the fixed block rates are the least regressive and are the most advantageous for the lower and middle income groups. The wealthiest households are only slightly better-off under EMWD's ABR than under fixed block rates.

These results naturally raise questions about affordability. To explore this further, we follow the approach proposed by García-Valiñas *et al.* (2010) and compute an affordability index *AI* defined as follows:

$$AI = \frac{MBW}{Income}$$

where *MBW* is the amount of money a household would pay to cover basic water needs and *Income* is household income. As suggested by Reynaud (2008), if households spend more than 3% of their income to pay for basic water they may be considered “water-poor”. That is, there may be affordability concerns if *AI* takes values higher than 3%. To implement this test, we consider two measures for basic water needs. The first is the size of the first block (for Tariffs 1, 2 and 5), as this block is intended for indoor uses. For the second, we assume that the per capita basic water needs are equal to 100 liters (26.4 gallons) per day (Howard and Bartram, 2003). Table 6 shows that *AI* is very low in all cases, implying that none of the tariffs introduces worrisome affordability concerns.

Regarding the distribution of EV by baseline water use, we observe in table 5 that the lowest water users (1st tercile) are largely unaffected by three of the price-based policies (Tariffs 1-3). In fact, this group experiences a small welfare increase under two of these policies, and a more substantial increase under the fourth price-based policy (Tariff 5). However these households incur a noticeable welfare decrease under the quantity restriction. This makes intuitive sense because low use households will be relatively more susceptible to changes in the fixed charge, which increases substantially under Tariff 4 (notably, the increase is similar in magnitude to the estimated welfare loss for this group). The result for Tariff 5 also makes sense because it is the low use households that stand to benefit from a combination of reduced block sizes and prices. Households in the 2nd tercile experience relatively large welfare increases under Tariffs 1 and 2 compared to moderately large welfare decreases under Tariffs 3 and 4, and little change under Tariff 5. Households in the 3rd tercile experience welfare losses under all policies but fare relatively better under Tariffs 1 and 2. The results for these groups again are intuitive, especially for the price-based policies, because larger users tend to fare worse under price increases. Apparently the 2nd tercile users reap significant benefits from the lower-priced tiers, thus avoiding large welfare losses, whereas the largest users are more impacted by the higher-priced tiers.

In addition to income and water use level, we also consider how water use efficiency may correlate with welfare effects. Understanding how pricing policies affect customers along this dimension is relevant for water suppliers who often face resistance from their more miserly customers when asked, along with their more profligate neighbors, to reduce water use even further during periods of increased water scarcity. To investigate this question, we estimate ordinary least squares regressions of household equivalent variation on a constant, income, water consumption prior to the rate change, and water use efficiency prior to the rate change. Efficiency is measured as the ratio of a household's consumption to its water budget, so higher values correspond to less efficient households. Table 7 summarizes the coefficients from these regressions. The table shows that the two allocation-based rate structures are noticeably different from the other policies: they are the only policies under which the induced welfare change is positively (and strongly) correlated with water use efficiency. In other words, more efficient households tend to "do better" than less efficient households under allocation-based rates, while the reverse holds for the other policies. In practice, this could prove to be an obstacle to public acceptance of these other policies, especially for fixed block rates. Under all policies, lower usage households tend to "do better" than higher usage households (particularly under fixed blocks); and again the mildly regressive nature of these policies can be seen in the small but positive coefficients on income.[21]

# 4. Conclusions

We find that the adoption of allocation-based block rates by EMWD increased the welfare of sample households by an average of $24 annually while reducing consumption by around 17%; however the average welfare of households with incomes in the lower tercile was reduced slightly, implying that the rate structure is somewhat regressive. Households with relatively high water consumption also were negatively impacted by the policy. Nonetheless, overall 62% of the sample households were made better-off.

Our analysis of the welfare changes associated with four alternative rate structures that achieve the same levels of consumption and revenue finds that a similar fixed block rate slightly outperforms EMWD's allocation-based rates, increasing household welfare by an average of $28 annually and making 66% of households better-off. However households made worse-off under fixed blocks can experience welfare losses twice as large as those made worse-off under allocation-based rates. This mean-variance trade-off in welfare outcomes could be an important policy-consideration for rate-makers. Future work could further explore this trade-off, and investigate how welfare effects depend on the specific features of block rate structures so they might be designed more deliberately to enhance consumer welfare.

[21] We also considered a regression with both linear and quadratic terms for income, consumption and efficiency. Not all coefficient estimates are significant across all models, but when we calculate marginal effects using all coefficient estimates, the directions of the effects are unchanged and the magnitudes are very similar to those reported in table 7.

The other block rate structure examined here, a “pro-environment” allocation based rate, appears to be dominated by EMWD’s ABR structure in terms of the selected welfare measures. However, it is noteworthy that the pro-environment ABR also produces a slight overall improvement in welfare and makes 54% of households better-off. Moreover, our regression results show that the correlation between welfare improvement and water use efficiency is strongest under this rate structure, implying that this rate structure tends to “reward” efficient users much more than do the other rate structures. This could be an important consideration for water districts facing opposition to rate increases from customers who have already incurred costs to improve their water use efficiency.

Regarding the two remaining alternative policies – a uniform rate increase and a quantity restriction – our results indicate that these policies tend to decrease overall welfare. The former makes a small proportion of households better-off (17% of the sample households), whereas the latter does not improve welfare for any consumer. However, one unexpected result is that the quantity instrument performs slightly better than the price instrument: the quantity restriction with fixed cost increase is, on average, $1.68 better per year than the price increase with fixed cost decrease. Sensitivity analyses suggest that this result is related to the stochastic elements of the model: setting the variances of both error terms equal to zero produces the more intuitive result that aggregate welfare under the price instrument is higher than under a uniform quantity restriction. However these differences are small, and the stochastic elements of the model play important roles in the simulations. Additional work in this area would be helpful for better understanding these relationships.

Moreover, we show that the DCC framework is not only a useful tool for predicting water demand, but also valuable for policymakers aiming to understand the welfare consequences of nonlinear pricing policies. Given the characteristics of water as a scarce but also essential good, our analysis can help guide the development of pricing policies in order to promote customer welfare while also achieving sustainable levels of consumption and full cost recovery for water suppliers.

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Table 1: Summary statistics.

| Variable | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|
| Consumption (CCF/month)[a] | 20.70 | 21.14 | 20.12 | 20.77 | 20.99 | 19.74 | 17.77 | 15.99 | 15.73 |
| Average block 1 size (CCF/month) | | | | | | | 7.99 | 8.40 | 8.65 |
| Average block 2 size (CCF/month) | | | | | | | 16.44 | 15.69 | 16.92 |
| Average block 3 size (CCF/month) | | | | | | | 12.46 | 12.30 | 13.03 |
| ET (in/month)[b] | 4.67 | 4.87 | 4.59 | 4.73 | 4.87 | 4.81 | 4.70 | 4.55 | 4.85 |
| Conservation requests | 0.17 | 0.00 | 0.08 | 0.25 | 0.08 | 0.08 | 0.08 | 0.00 | 0.08 |
| Nominal price ($/CCF) | 1.43 | 1.46 | 1.53 | 1.62 | 1.69 | 1.85 | 1.27<br>2.33<br>4.17<br>7.63 | 1.43<br>2.61<br>4.68<br>8.56 | 1.44<br>2.64<br>4.73<br>8.65 |
| Nominal average price paid ($/CCF) | | | | | | | 1.93 | 2.10 | 2.05 |
| Real price (2010$/CCF) | 1.66 | 1.66 | 1.68 | 1.72 | 1.77 | 1.86 | 1.30<br>2.37<br>4.25<br>7.78 | 1.43<br>2.61<br>4.68<br>8.56 | 1.39<br>2.54<br>4.55<br>8.33 |
| Real average price paid (2010$/CCF) | | | | | | | 1.98 | 2.10 | 1.98 |
| Real budget (2010$/month) | 316.26 | 317.45 | 318.05 | 319.20 | 320.78 | 316.70 | 311.07 | 309.96 | 309.44 |
| Household size (#) | | | | | 3.53 | | | | |
| Irrigated area ($ft^2$) | | | | | 4,177 | | | | |
| Education[c] | | | | | 0.50 | | | | |

[a] CCF = hundred cubic feet.
[b] A principle components analysis on all available weather data during the observation period for one of the CIMIS stations reveals that ET captures 94% of the total weather variability.
[c] Fraction of residents reporting at least some college education.
[d] Observed increases in the average block 1 size are due to larger indoor variances.

Table 2: Block-rate model parameter estimates and standard errors (n=569,730).

| **Variable** | **Description** | **Estimate (Std Err)** |
|---|---|---|
| *Constant* | Constant | 1.5550 (0.0080) |
| *Education* | Fraction of census tract residents reporting "at least some college" or more education | 0.5556 (0.0076) |
| *HHS* | Household size (# of persons) | 0.1347 (0.0007) |
| *IA* | Irrigated area (1000 sq ft) | 0.0295 (0.0002) |
| *Spring* | Dummy for Apr-Jun | 0.2335 (0.0046) |
| *Summer* | Dummy for Jul-Sep | 0.5185 (0.0057) |
| *Fall* | Dummy for Oct-Dec | 0.4670 (0.0033) |
| *Conserve* | Dummy for conservation request | -0.1350 (0.0070) |
| *ET* | ET (in/month) | 0.1140 (0.0013) |
| *Time trend* | Linear annual increments | -0.0727 (0.0009) |
| *Het Pref* | Persistent preference heterogeneity | 1.1106 (0.0028) |
| $p_{it}$ | Real price | -0.2201 (0.0019) |
| $d_{it}$ | Real money budget | 0.0001 (8e-7) |
| $\sigma_{\varepsilon}$ | Standard deviation for $\varepsilon$ | 0.5676 (0.0015) |
| $\sigma_{\eta}$ | Standard deviation for $\eta$ | 0.2386 (0.0012) |

All estimates are significant at the 1% level.

Table 3: Prices and distributions of households under the tariffs considered in the analysis

| | | Baseline | Tariff 1: Allocation-based rates | Tariff 2: Fixed block rates with price and fixed cost adjustments | Tariff 3: Uniform price increase with fixed cost decrease | Tariff 4: Quantity restriction with fixed cost increase | Tariff 5: Pro-environment allocation-based rates |
|---|---|---|---|---|---|---|---|
| Price | Fixed fee | 9.86 | 10.04 | 12.80 | 1.94 | 16.69 | 12.88 |
| | Block 1 | 1.87 | 1.37 | 1.21 | 2.70 | 1.87 | 1.04 |
| | Block 2 | | 2.50 | 2.21 | | | 1.90 |
| | Block 3 | | 4.49 | 3.96 | | | 3.41 |
| | Block 4 | | 8.21 | 7.24 | | | 6.24 |
| % of households | Block 1 | NA | 28.1% | 13.7% | NA | NA | 0.7% |
| | Block 2 | | 59.3% | 75.2% | | | 94.5% |
| | Block 3 | | 10.8% | 11.0% | | | 4.7% |
| | Block 4 | | 1.8% | 0.1% | | | 0.1% |

Table 4: Equivalent variation statistics for the four policies

| | **Tariff 1: Allocation-based rates** | **Tariff 2: Fixed block rates with price and fixed cost adjustments** | **Tariff 3: Uniform price increase with fixed cost decrease** | **Tariff 4: Quantity restriction with fixed cost increase** | **Tariff 5: Pro-environment allocation-based rates** |
|---|---|---|---|---|---|
| Minimum EV ($/month) | -170.93 | -357.81 | -139.95 | -16.41 | -221.46 |
| Mean EV ($/month) | 1.98 | 2.32 | -7.40 | -7.26 | 0.06 |
| Median EV ($/month) | 5.70 | 7.78 | -5.82 | -7.16 | 2.19 |
| Maximum EV ($/month) | 168.28 | 170.36 | 7.10 | -6.69 | 125.33 |
| # of better-off households | 8455 | 9015 | 2298 | 0 | 7277 |
| % of better-off households | 62% | 66% | 17% | 0% | 54% |

Table 5: Mean equivalent variation by income and baseline water use terciles

| | | **Tariff 1: Allocation-based rates** | **Tariff 2: Fixed block rates with price and fixed cost adjustments** | **Tariff 3: Uniform price increase with fixed cost decrease** | **Tariff 4: Quantity restriction with fixed cost increase** | **Tariff 5: Pro-environment allocation-based rates** |
|---|---|---|---|---|---|---|
| Income | 1st tercile | -1.57 (-0.6%) | -0.82 (-0.3%) | -7.51 (-2.7%) | -7.30 (-2.6%) | -1.30 (-0.4%) |
| | 2nd tercile | 2.51 (0.8%) | 3.12 (1.0%) | -6.78 (-2.1%) | -7.23 (-2.3%) | 0.32 (0.1%) |
| | 3rd tercile | 4.99 (1.4%) | 4.66 (1.3%) | -7.90 (-2.2%) | -7.24 (-2.0%) | 1.15 (0.3%) |
| Baseline water use | 1st tercile | 0.30 (0.1%) | 0.84 (0.3%) | -0.56 (-0.2%) | -6.97 (-2.4%) | 8.68 (2.9%) |
| | 2nd tercile | 7.15 (2.2%) | 11.05 (3.5%) | -6.43 (-2.1%) | -7.19 (-2.3%) | -0.32 (-0.2%) |
| | 3rd tercile | -1.51 (-0.5%) | -4.94 (-1.8%) | -15.20(-4.9%) | -7.61 (-2.4%) | -8.19 (-2.7%) |

Numbers in parentheses express the welfare effects as percentages of the monthly money budget.

Table 6: Affordability index for the four policies

| | Tariff 1: Allocation-based rates | | Tariff 2: Fixed block rates with price and fixed cost adjustments | | Tariff 3: Uniform price increase with fixed cost decrease | | Tariff 4: Quantity restriction with fixed cost increase | | Tariff 5: Pro-environment allocation-based rates | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Mean** | **Std Dev** | **Mean** | **Std Dev** | **Mean** | **Std Dev** | **Mean** | **Std Dev** | **Mean** | **Std Dev** |
| MWB: 1st block | 0.042% | 0.016 | 0.045% | 0.015 | | | | | 0.032% | 0.011 |
| MWB: 100 liters | 0.029% | 0.010 | 0.033% | 0.011 | 0.023% | 0.008 | 0.045% | 0.015 | 0.032% | 0.011 |

Table 7: Equivalent variation regression coefficients across policies

| | **Tariff 1: Allocation-based rates** | **Tariff 2: Fixed block rates with price and fixed cost adjustments** | **Tariff 3: Uniform price increase with fixed cost decrease** | **Tariff 4: Quantity restriction with fixed cost increase** | **Tariff 5: Pro-environment allocation-based rates** |
|---|---|---|---|---|---|
| Constant | -26.4059 | -21.937 | -6.3713 | -7.5571 | -10.7522 |
| Income | 0.1152 | 0.1027 | 0.0386 | 0.0030 | 0.1167 |
| Consumption | -0.1566 | -0.9082 | -0.6741 | -0.0361 | -0.0650 |
| Efficiency | -5.1170 | 12.6044 | 0.3408 | 0.0910 | -28.3599 |

All estimates are significant at the 1% level.

Figure 1: Utility maximization under an IBR tariff

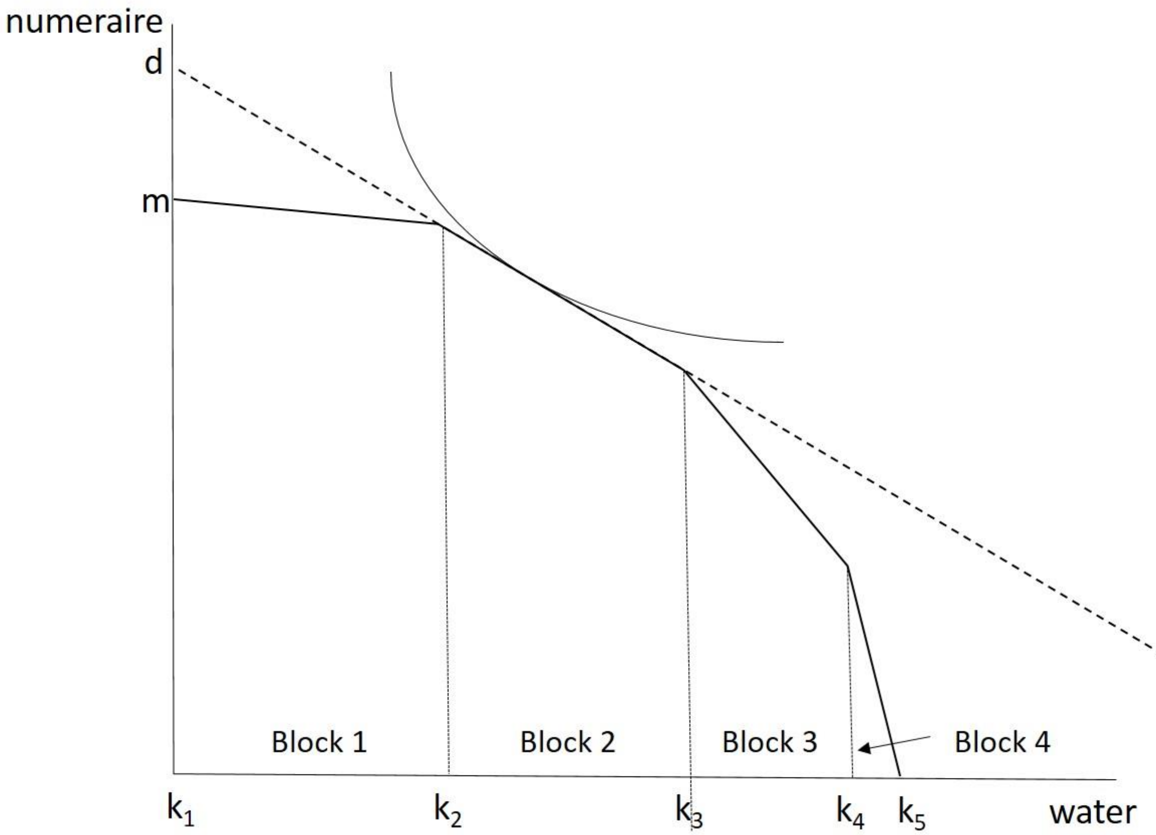

Figure 2: Utility maximization after a change in price in the 2nd block

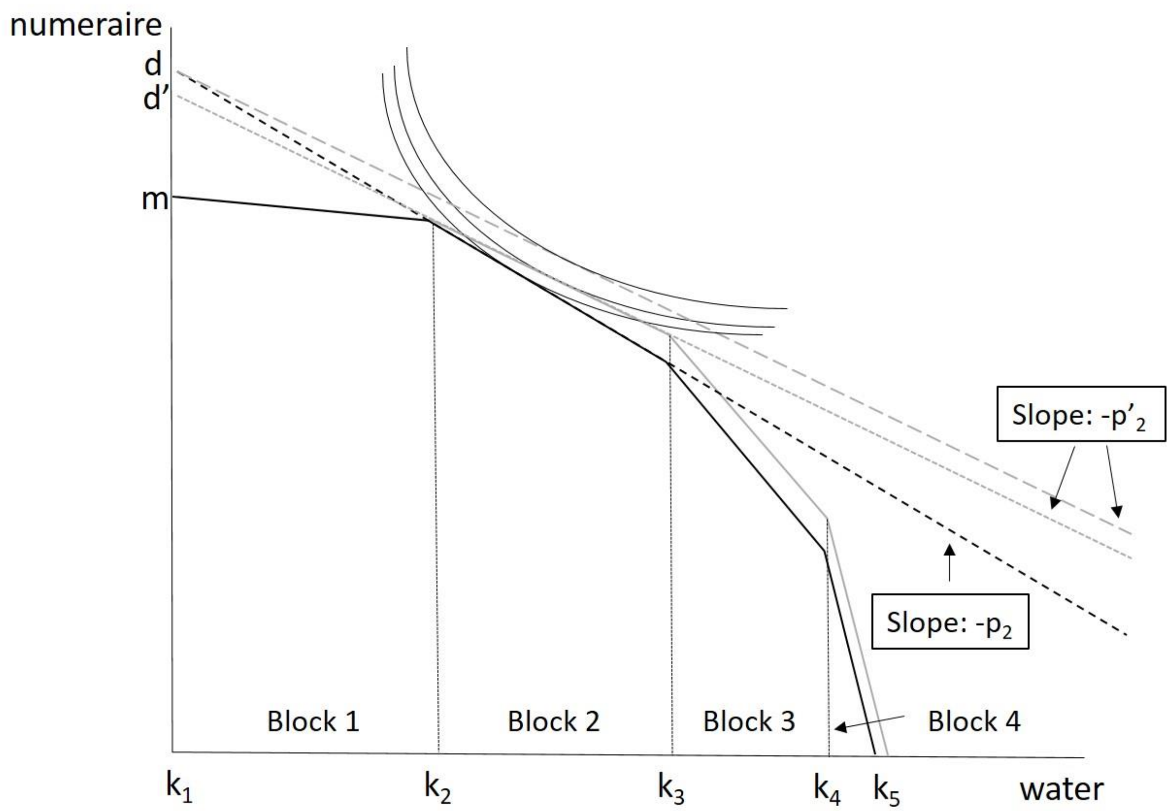

Figure 3: Tariff structures before and after the change

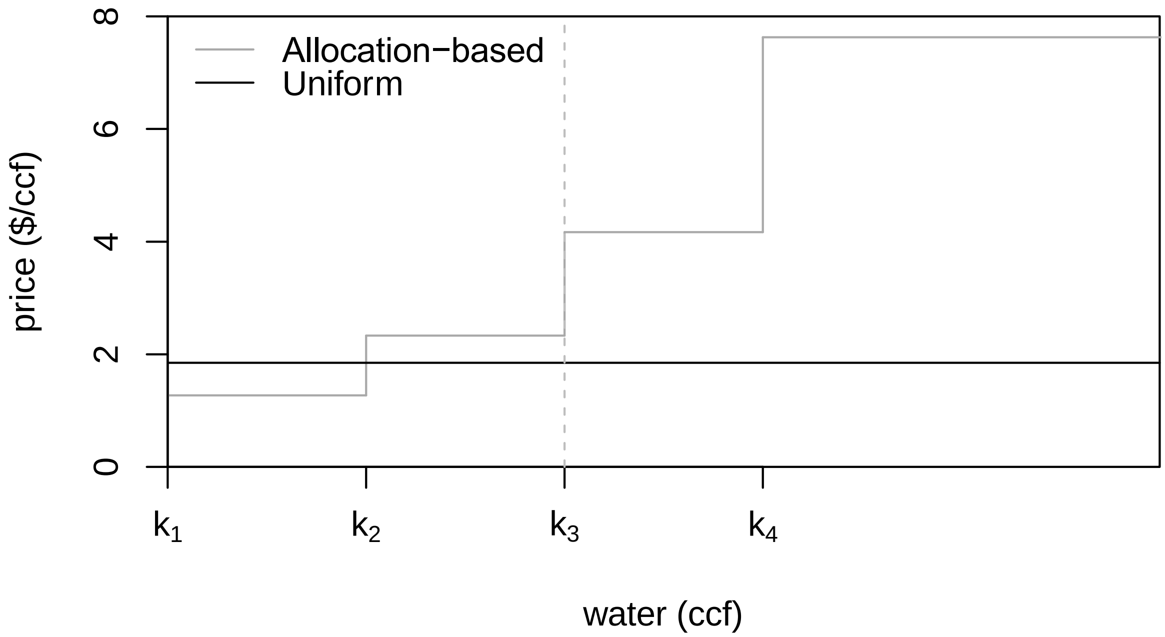

Figure 4: Observed vs. predicted average monthly household usage under block rates.