Modeling effects of multiple conservation policy instruments and exogenous factors on urban residential water demand through household heterogeneity

Elena Tchigriaeva,
Graduate Research Assistant, Department of Economics, University of Nevada, Reno

Corey Lott,
PhD Student, Department of Economics, University of California, Santa Barbara

Kimberly Rollins,[i]
Professor, Department of Economics, University of Nevada, Reno

Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2014 AAEA Annual Meeting, Minneapolis, MN, July 27-29, 2014.

[i] Corresponding Author; Tel. 775.784.1677; Fax. 775.784.1773

Modeling effects of multiple conservation policy instruments and exogenous factors on urban residential water demand through household heterogeneity

Elena Tchigriaeva,
Graduate Research Assistant, Department of Economics, University of Nevada, Reno

Corey Lott,
PhD Student, Department of Economics, University of California, Santa Barbara

Kimberly Rollins,
Professor, Department of Economics, University of Nevada, Reno

Abstract: In response to rapid population increases and limited water supplies water utilities in semi-arid Western states have implemented multiple water conservation programs, including rebates to clients who replace turf with native plants. This article demonstrates the effect of these programs on water demand, controlling for exogenous influence of weather and property characteristics.

Acknowledgements: This project has received support from the Nevada EPSCoR Program, Nevada Agricultural Experiment Station, Southern Nevada Water Authority and the Las Vegas Valley Water District.

Introduction

Outdoor water use is the largest and most variable component of residential water use in the western United States, where almost all precipitation occurs during winter months and arid conditions require irrigation to maintain most types of residential and commercial landscaping (Sovocool et al. 2006; Hilaire et al. 2008; Kenney et al. 2008)[1]. Residential outdoor water demand is determined by customer decisions over landscape vegetation, irrigation technology, irrigation amount; the presence and structure of demand management programs and policies; as well as by weather and climatic factors that affect the length of irrigation season and water use, but are out of the customer's control. Understanding these components of seasonal water consumption and their contributions to water demand is a key to developing municipal water use and conservation plans that are economically efficient and flexible in reaching water conservation goals[2].

Conservation programs that target irrigation are generally of three types. First, outreach and education programs instruct homeowners on best irrigation practices and provide information on drought resistant landscaping. Second, voluntary incentive programs offer rebates and other incentives for homeowners to alter landscaping to reduce irrigation requirements. Third, mandatory programs impose irrigation restrictions as well as use zoning ordinances that limit the amount of turf allowable on properties. Education and outreach are relatively inexpensive, but conservation outcomes are difficult to predict because these programs do not address incentive problems that support or hinder conservation decisions[3]. Voluntary incentive-based programs incur costs associated with the size of the rebates, which in turn influences the number of customers who participate, the total area of landscape converted, and thus water conserved. These features of voluntary incentive-based programs make it difficult to evaluate their cost-effectiveness before implementation. Mandatory programs involving zoning and irrigation restrictions do not require rebates or subsidies, but incur costs associated with monitoring and regulation, and generate other types of costs associated with rigidity of restrictions (Castledine et al 2014). Municipal water utilities often employ multiple conservation programs simultaneously. For example, all three are in use in the municipalities within the Southern Nevada Water Authority (SNWA), which includes the Las Vegas municipal area.

In regions where landscape irrigation is an important driver of water demand, municipal water agencies face two problems in predicting how water demand is affected by conservation programs. First, predictions of water demand will depend in large part on the type of landscape vegetation that is being irrigated and climate conditions under key parts of the growing season. Despite this, most water demand models do not include vegetation and weather variables together. Second, a municipal water agency's ability to determine what combination of conservation strategies would best achieve a given conservation goal requires a model that is capable of analyzing multiple simultaneously applied conservation strategies.

Simulation methods based on evapotranspiration differentials among vegetation types have been used to calculate maximum water savings as a function of the total amount of one type of vegetation that is substituted for another (SNWA Conservation Plan 2009). However, biophysical approaches cannot account for many factors that affect customers' decisions regarding landscaping and the amount of irrigation they choose to apply. An econometric water demand model, on the other hand, could in theory account for multiple effects on demand, including price, household characteristics, landscaping, conservation programs, and other variables. As well, they could isolate how clients' responses to any one program variable (price, for instance) is affected by levels of other variables (type of vegetation, climate, season). We are not aware of any previous economic studies that incorporate the components necessary to explicitly evaluate the effect of residential landscape vegetation on water demand and on outcomes of water demand management policies.

In this paper, we develop and estimate a model with four categories of factors that influence residential irrigation water demand following Kenney et al. (2008). These are exogenous factors, pricing policies, voluntary conservation incentives, and mandatory (involuntary) conservation regulations. Exogenous factors include precipitation, temperature, wind speed, month, individual property and household characteristics, and economic trends. We use a random effects model with five years of monthly billing data for residential clients in the Las Vegas, Nevada region; with data that provides surface area for two landscape vegetation types for each property; daily weather data; and property tax assessor data to determine property characteristics and to proxy household characteristics. The two landscape variables for each property (area in square feet devoted to turf and area devoted to trees and shrubs native to arid climates) provide the means to evaluate change in water demand associated with converting turf to low-water-use landscaping. Monthly period dummy variables capture the effects of economic trends, as well as seasonality. We use the results of our estimated model to demonstrate the effect of vegetation, weather, and demand management policies on water demand.

To our knowledge, no previous models of water demand include all, or even most of the features outlined above. Most existing studies focus on limited sets of factors that influence water demand. Importantly, the vast majority rely on data with some degree of aggregation over time and spatially over clients. Studies that control for the effect of landscape vegetation on water demand include Fox et al. (2009), who use a dummy variable to indicate the presence of a garden, and Wentz and Gober (2007), who use the percent of irrigated residential properties per census tract in a cross-sectional aggregated dataset. Al-Qunaibet and Johnston (1985) include temperature, wind speed, income and price as explanatory variables. Kenney et al. (2008) analyze the effects of temperature, precipitation, house age, family size and conservation programs on water demand. Renwick and Archibald (1998) develop an econometric model that incorporates endogenous technological change at the household level, but they use few other factors. Campbell et al. (2004) work with a relatively large set of independent variables and monthly data from more than 19,000 households from 1990 to 1996; however, most of the variables track conservation programs, and household characteristics are aggregated by census track.

Several studies demonstrate that heterogeneity associated with differences in household residence and demographics influence residential water demand (Arbués et al. 2003; Worthington and Hoffmann 2008). Blundell et al. (1992) describe advantages of individual-level data over aggregated data to capture heterogeneity of preferences, avoid aggregation biases and to produce robust demand function parameter estimates. Baltagi (1995) notes that data aggregated over individual users can result in biased standard errors and unreliable t-values for because it cannot account for the effects of unobservable time invariant individual characteristics on water use. Moeltner and Stoddard (2004) demonstrate a variant of this result using commercial water use data. While data disaggregated to the billing-period and client-level is therefore preferable (Schefter and David 1985; Saleth and Dinar 2000), the literature contains only a limited number of papers using data disaggregated at this level (Hanke and de Mare 1982; Jones and Morris 1984; Nieswiadomy and Molina 1989; Hewitt and Hanemann 1995).

Panel data models provide more efficient and consistent estimates of coefficients for household level water demand models than OLS methods (House-Peters and Chang 2011; Polebitski and Palmer 2010; Nauges and Thomas 2003; Arbues et al. 2004). The majority of studies use panel data where time observations are annual, semi-annual, bimonthly, or monthly (Lyman 1992; Höglund 1999; Nauges and Thomas 2000). Less frequent observations make it difficult to isolate the relationship between variation in weather conditions and water use. Overall, monthly or a modified daily panel (in which billing period start and end dates vary over households in a sample, and daily weather conditions are averaged over the billing period in each observation), as we use, is most desirable for identifying the effect of weather conditions on household water consumption. Our model uses a fully disaggregated approach with monthly billing data over a 5-year period from the Las Vegas metropolitan region in Nevada.

The Las Vegas Region

The Las Vegas Valley has a subtropical desert climate with extremely high summer temperatures, an evapotranspiration water requirement of nearly 90 inches, and an average annual 4.5 inches of precipitation (Sovocool and Morgan, 2006). The purpose of the Southern Nevada Water Authority (SNWA) is to plan and provide for present and future water needs of the region. SNWA member agencies serve about 96% of Clark County's population, of over 2 million people (Sovocool and Morgan, 2006; U.S. Census Bureau). The region experienced dramatic population growth rates during the last decades, slowing during the last recession. A majority of Clark County residents (60.3%) live in single-family houses, which account for approximately 44.5% percent of regional water use (SNWA 2009). Southern Nevada gets nearly 90 percent of its water supply from the Colorado River, sharing this source with six neighboring states plus Mexico. The SNWA has rights to consumptive use of 300,000 acre-feet of Colorado River water annually. The SNWA earns return flow credits for treated wastewater that is returned to Lake Mead via the Las Vegas Wash. These return flow credits allow the SNWA to withdraw water in excess of Nevada's consumptive use apportionment.

The SNWA has implemented several water conservation programs. Pricing is based on increasing block rate structures designed to encourage efficiency, while ensuring affordability for essential uses. The SNWA also uses a variety of non-price mandatory conservation regulations. While the SNWA actively promotes indoor conservation, the greatest opportunity for water conservation lies in curbing outdoor water use, which does not generate return flow credits for Colorado River water (SNWA 2009). In 2003, the SNWA enacted a regulation that prohibits turf from the front yards of all new single-family residential homes and limits turf to no more than 50% of back and side yards (Hutchins-Cabibi et al. 2006; SNWA 2009).

The SNWA also uses several voluntary conservation programs. Rebates are given toward the purchase of rain sensors that shut down residential irrigation systems during and after rain, for installation of devices that automatically adjust watering schedules according to the weather, and for the purchase of pool covers. The largest incentive program is the water smart landscape (xeriscape) rebate program that encourages residential and commercial owners to convert grass (turf) to water-efficient desert landscaping using trees and shrubs. This program is available to property-owners who initially have over 400 square feet of turf, and requires that after conversion at least 50% of the area contains vegetation in the form of trees and shrubs that grow well in the arid climate. Currently the program rebates \$1.50/square foot for the first 5,000 square feet of lawn removed and \$1 for additional square foot removed, up to a maximum of \$300,000 per property. Since program inception, more than 130 million square-feet of lawn have been replaced, saving an estimated 7 billion gallons of water annually (SNWA, 2009).

Model and Methods

Our approach to modeling price follows the previous literature. Earlier studies assessed the use of average price versus marginal price (Foster and Beatty 1979, Howe and Linaweaver 1967, Billings and Agthe 1980), difference[4] variable to account for block rate structure and income effects, and use of instrumental variables to treat endogeneity of marginal price and quantity of water used (Taylor 1975; Nordin 1976). Nieswiadomy and Molina (1989) use two-stage least squares (2SLS) and instrumental variables (IV) techniques to control for the endogeneity of marginal price as well as the difference variables. Numerous other authors use two stage least squares or instrumental variables techniques to handle the endogeneity of price and quantity (Jones and Morris 1984; Deller et al. 1986; Agthe et al. 1986; Agthe and Billings 1987; Höglund 1999; Nauges and Thomas 2003; Hewitt and Hanemann 1995).

We use a random effects model to accommodate household heterogeneity. The model is composed of a water demand equation (1), in which water demand by household *i*, in month *t* is expressed as:

$$ln(y_{it}) = \hat{p}_{it}\beta_p + \hat{d}_{it}\beta_d + x_i'\beta_x + c_i'\beta_c + m_t'\beta_m + \varepsilon_{it} \qquad (1)$$

and two price equations: marginal price (2) and the difference (3).

$$p_{it} = b_i' \beta_{b_{it}} + x_i' \beta_x + c_t' \beta_c + m_t' \beta_m + \varepsilon_{itp} \qquad (2)$$

$$d_{it} = b_i' \beta_{b_{it}} + x_i' \beta_x + c_t' \beta_c + m_t' \beta_m + \varepsilon_{itd} \qquad (3)$$

where p_{it} is the observed marginal price of water associated with household *i* and month *t*; d_{it} is the observed difference, x_i is a *k* by 1 vector of factors exogenous to demand management policies, c_i is a *l* by 1 vector of factors targeted for non-price policies, m_t is a *n* by 1 vector of period indicator variables corresponding to time period *t*, the β-terms are parameters corresponding to their associated regressors, and ε_{it} is and error term which is decomposed into a household-specific constant μ_i and a normally distributed random error term e_{it}.

The price equations capture the influence of endogenous price effects on demand under block rate schedules since the marginal price depends on the quantity demanded. Marginal price p_{it} and difference d_{it} are regressed against block prices, flat fee (vector b_i), factors exogenous to demand management policies, and factors targeted by demand management policy. Predicted values for price, $\hat{p}_{it}$ and difference, $\hat{d}_{it}$ are used as regressors in the water demand equation, the second stage. The m_t vector of period variables is used to control for unobserved time effects that may result from exogenous regional economic conditions and the timing of price changes.

Variables and Data

Our data consist of 3,525,368 observations based on 5 years of monthly billing data from 2007 to 2001 from 59,752 households in the Las Vegas area. The data include single-family residential customers that satisfy 4 criteria: observations must have billing periods of between 23 to 37 days; an uninterrupted consumption history for the study period; property and building characteristics available from the county assessor datasets; and households have not participated in voluntary water conservation programs. We use the last criterion because we employ differences in water use by proportion of property that is composed of different landscape vegetation type to proxy expected differences from changing landscape type. Water use data from properties that changed cover type within the 5-year period would experience a one to two-year temporary increase in water use while the new landscaping is becoming established, before the permanent watering regime becomes evident.

While our 5 year period is too short to accommodate establishment of new landscaping, the variation in landscape type in our data is sufficient for estimating expected change in water use with a change in landscape. Data provided by the SNWA and described by Brandt (2008) contains for each billing customer the square feet of turf and the square feet of shrubs/trees. These data were generated through use of aerial imaging, property tax assessor parcel boundaries, and spatial analysis algorithms to interpret image data into landscape type. We use the estimated model to calculate elasticities of demand that include these landscape types.

We account for seasonal and inter-annual variation in weather conditions by including average temperature, days of rainfall, and average wind speed for each billing period. Billing periods vary over the sample due to the fact that different homes are on billing cycles that start and end on different days of the same month. We calculate monthly averages from daily weather measurements obtained from the nearest weather station in NOAA's Global Historical Climate Network database during each day of each monthly billing period and exploit this variation in weather conditions within and among seasons and over the years in the data. The panel captures annual variation in weather variables, thus characterizing variations in seasonality[5].

Most water demand models include one or more weather variables to control for the influence of weather on seasonality of residential water use. Some studies use indices of weather effects, including evapotranspiration rates (Billings and Agthe 1980; Agthe et al. 1986; Nieswiadomy and Molina 1988; Hewitt and Hanemann 1995; Bamezai 1997); the number of days without a significant rainfall times the average monthly temperature (Griffin and Chan 1990; Gaudin et al. 2001); lagged precipitation and average temperature (Pint 1999); relative humidity (Al-Quanibet and Johnston 1985); and growing and cooling degree days (Lyman 1992). A criticism of the use of indices of weather effects is that by aggregating weather information, they mask the weather conditions as decision makers observe them. We assume that decision-makers observe and react to specific weather events (by adjusting irrigation timing before heading out to work, or before turning in for the evening in response to weather reports or expectation of heat and precipitation events), and therefore use billing cycle averages for temperature, days of precipitation, and wind speed as weather variables.

While most previous empirical models of water demand that include weather effects specify the effect of precipitation as linear, Maidment and Miaou (1986) and Miaou (1990) argue that precipitation events initially reduce water demand with a diminishing effect over time. This approach makes sense for areas that receive frequent and considerable quantities of precipitation; however rainfall is generally infrequent and of short duration during the irrigation season for our study area, where a single spring or summer precipitation event may cause residents to skip a day of outdoor irrigation but will not impact cumulative irrigation days. Therefore, we treat monthly precipitation as a count variable for days of precipitation, rather than as quantity of precipitation, following Martínez-Espiñeira (2002).

Additional variables include a proxy for monthly income based on the assessed value of the house and property, following Nieswiadomy and Molina (1988), obtained from property tax records. The number of bedrooms is used to proxy family size. Other independent variables include the number of days in the billing period, marginal price, difference, presence of a swimming pool, a dummy to indicate whether the home was built after the 2003 introduction of the turf restriction policy, and period dummy variables. The dependent variable in all specifications is the natural logarithm of monthly water consumption in 1,000's of gallons. Tables 1 and 2 summarize the variables and descriptive statistics for the data.

Table 1. Variable Descriptions

Table 2. Descriptive Statistics

Results

Table 3 summarizes the second stage regression results. The overall R^2 of 0.47 indicates a high goodness of fit for this type of data. A Hausman test verifies our use of a random effects model, as well as the inclusion of period dummy variables. Results are robust and signs in accordance with expectations. Coefficients for marginal price, days of precipitation, non-irrigated area, and turf restriction policy negatively affect water demand. The difference variable is negative, as demonstrated by Nordin (1976). Coefficients for days, family size, income, average temperature, average wind speed, pool presence, size of turf, and size of trees positively affect water demand.

Table 3. Second Stage Regression Coefficient Estimates

The estimated model indicates that an increase of average temperature by 1 degree Fahrenheit leads to an increase in water demand per household of about 0.9%; relatively close to the 1% reported by Harlana et al. (2009) for Phoenix, Arizona. An increase in wind speed increases water demand by 1.4%, and an additional day of precipitation decreases water demand by 0.8% monthly. An additional bedroom contributes to a 9.2% increase in water demand. A $1,000 increase in income increases water demand by 4%.

More essential for water management policy are the following estimated parameters. The presence of a swimming pool increases water use on average by 5.9% per month. The turf restriction policy implemented on homes built after 2003 contributes a 9% decrease in water use. Increasing turf area by 10 sq. feet and tree area by 10 sq. feet increases water use by 0.29% and 0.13% monthly. It is important to point out that the coefficient for size of turf area is twice as large and significantly different from that for size of treed area. The period dummy variables pick up unobservable effects that are correlated with time. These exhibit seasonality and reflect the recent economic recession (see Figure 1).

Figure 1. Plot of Period Dummy Variables.

Table 4 summarizes estimated elasticities. Our inelastic price (-0.34) and income (0.13) findings are consistent with other residential water studies. According to Worthington and Hoffman (2008) the majority of residential water demand studies have estimated price elasticities of between 0.0 and 0.5 in absolute terms. In a meta-analysis of 64 residential water studies, Dalhuisen et al. (2003) found an average and median price elasticity of -0.41 and -0.35 respectively, and an average and median income elasticity of demand of between 0.43 and 0.24. Our average and median price elasticities of -0.34 and -0.31 is consistent with the mean for the Dalhuisen et al. study and our average and median income elasticities of 0.13 and 0.12 while somewhat low, are well within the range of income elasticities from similar studies.

We find that residential water users in our sample are most responsive to changes in temperature (0.61 and 0.60 for average and median respectively). Nevertheless, despite an inelastic response, price can significantly influence water demand. For instance, increasing price by 10% (from a mean of $2.31 to $2.54) will decrease water consumption by 3.4%, which is on average 408 gallons per month (4.9 thousand gallons annually) per household.

Table 4. Average Elasticities of Demand for Selected Explanatory Variables

Applications of Results

In this section we demonstrate the use of the estimated model as an instrument for evaluating proposed water policy scenarios, using several examples. One advantage of using disaggregated data is the ability to calculate and analyze elasticities with respect to policy variables targeted by management for each observation of the dataset[6]. We are unaware of published applications of this approach, most likely because there are few examples of such disaggregated data sets that are as complete with explanatory variables[7]. The following applications are for demonstration purposes and use simplifying assumptions.

First, we use estimated coefficients to generate water demand projections for a scenario in which temperature is assumed to increase by 1 and 2 degrees F over 20 years. We assume for simplicity that the average temperature increases over time are deterministic and occur in a linear fashion. We use our estimated elasticities to determine what price increases would be required to induce water use reductions that compensate for the increased use predicted by the model for the temperature increase. As shown in Table 5, a $0.10 price increase (with savings of 42,722 gallons) would eliminate the increased water use from a 2 degree F increase (25,114 gallons), and more than compensate for a 1 degree F increase.

Table 5. Water Demand. 20 year Projections with increases in Temperature and Price

Our second example demonstrates alternative policy scenarios that rely on price and non-price water conservation policies to achieve a given conservation target. We use elasticities and the data to develop two portfolios that reduce water demand by about 17%, as shown in Table 6. The first portfolio is based on a 20% price increase with a 30% decrease in turf (presumably this decrease would be encouraged with a rebate program as described above and offered by SNWA). The second portfolio is based on a 30% price increase with a 20% decrease in turf area. Because elasticities are a function of the level of the explanatory variable and the specified change, instead of using average elasticities, we calculate price and turf elasticities for each of a series of levels of the explanatory variables (in Table 6, these levels are indicated as percentiles in the first column).

We calculate elasticities for 10%, 25%, 50%, 75%, and 90% quintiles as well as for the minimums, maximums, and means. Comparing the outcomes of the two scenarios, we see that the 17% water demand reduction is more evenly distributed among the percentile groups in the 2nd portfolio, where responses for the minimum (min) and maximum (max) users are 4.9% and 66.5% respectively. In portfolio 1, the main decreased water use is from the maximum group (with an 83.0% decrease in projected water use).

Table 6. Analysis of Elasticities of Policy Variables: Price and Turf Size

Next, we consider a voluntary program to replace turf with trees and shrubs. The SNWA offers such a program offering a rebate for every per square foot of turf replaced. In the SNWA program, property owners if they have over 400 square feet of turf, initially, and must replace the turf with at least 50% vegetated area consisting of approved drought-resistant trees and shrubs[8]. The following example, using our estimated elasticities and data, incorporates these restrictions and demonstrates how organizing information from the estimated model can aid in fine-tuning policies that target turf removal by indicating the effects of changing a minimal pre-conversion eligibility or converted area requirements. Figure 2 shows the estimated percentage of water savings for changes in residential area devoted to turf, where the horizontal axis represents the initial turf area and the vertical axis represents estimated elasticities of demand with respect to turf and trees. Line (1) in Figures 2 shows water savings from a 100% removal of the turf without replacement with trees and shrubs, line (2) shows water savings from a 100% turf removal where all turf area is replaced with trees and shrubs, and line (3) represents water savings when all turf is removed and replaced by trees and shrubs on 50% of the area. If we assume that the properties that remove turf are the ones that initially have over 400 square feet of turf, then the area between lines (3) and (2) to the right of 400 square feet of turf represents potential water savings from the SNWA program, as shown in Figure 2.

Figure 2. Percentage of Water Savings Depending on Initial Size of Turf and Size of Replaced Trees.

The histogram in Figure 3 orders residences in our data by turf elasticities. Residences with over 400 square feet of turf, and thus eligible for the SNWA program, are those with elasticities of demand with respect to turf of 0.11 and over. From this representation of the data, about 18% of residences qualify for the program, and about half of them have elasticities of no more than 0.2 (with 700 sq. ft. of turf area). The combined information from Figures 2 and 3 indicates that 50% of the qualified households would maximally save from 4% to 17.5% depending on post-conversion plant ratios. These results demonstrate how the capacity for this program is limited as the water savings from turf conversion is mined over time.

Figure 3. Percentage of Households by Elasticities of Water Demand in Respect to Turf.

Finally, we use our results to demonstrate how price elasticities of demand differ by landscape type as well as by season. Figure 4 shows mean elasticities of water demand with respect to marginal price (on the vertical axis) by month. The uppermost dotted line (1) represents residences in our data that do not have landscape vegetation on their property, and thus the water use by these residences can be used as an approximation of indoor water use. We see little seasonal variation (maximum of 0.2). The elasticity of about -0.25 for indoor water use indicates potential for water savings through price policies. The line (2) represents households with no turf, but some amount of trees and shrubs; line (3) represents households with less than 400 sqft of turf, that are therefore ineligible for landscape conversion conservation program; and the bottom line (4) represents marginal price elasticities for households with more than 400 sqft of turn that are eligible for the program. Notice that the information contained in Figure 4 could be developed for any price quintiles and for any combinations of turf and tree-shrub areas simultaneously. As expected, the largest turf areas consume more water during summer, and the qualitative estimations are clear. Seasonal responses are almost twice for households with over 400 sqft of turf (the difference between July and January elasticities is about 0.23). Households with less than 400 sqft of turf also indicate potential for price intervention (difference between July and January elasticities for having some turf households is about 013). To sum up, the information from the estimated model validates use of price policies in terms of their potential for reducing outdoor as well as indoor water use by residential customers.

Figure 4. Water Demand Elasticities in Respect to Marginal Price by Monthly Means.

In our final example of the use of the model results for policy analysis, we turn to pricing policies. As shown above, pricing can be an effective instrument for water conservation; however, its use may be limited due to public reluctance for approving price increases. On the other hand, the altering of thresholds and tiers in a block rate structure is an alternative for using price instruments that can address equity and other political concerns. The estimated coefficient on the model's difference variable can be used to predict the effects of manipulating thresholds. While the difference variable has been included in water demand models since Nordin (1976) introduced it to accommodate block rate pricing structures, it has been somewhat neglected as providing information for predicting response to pricing policy. Only Hewitt and Hanemann (1995) and Olmstead et al. (2007) use the difference variable as a part of budget constraint in their discrete/continuous choice model for developing more precise water demand estimations. By definition, the difference variable is the difference between the actual water bill and the hypothetical charges for the same amount of water used was charged the same rate as the price for the last block used. Equation (4) is easily derived from this definition[9]:

$$d_n = q_1(r_1\text{-}mp) + q_2(r_2\text{-}mp) + \ldots + q_{n-1}(r_{n-1}\text{-}mp) \quad (4)$$

where for n rate blocks q_i is the threshold quantity for each block, r_i is a block rate, and mp is marginal price. Notice that if we consider thresholds only, terms ($r_i - mp$) are fixed. For our model and data, the estimated demand elasticity with respect to difference for the mean is 0.23, which means a reduction in the ranges for the thresholds will increase difference and consequently reduced water demand, holding rate prices constant. Therefore, a decrease in threshold quantities by 50% will lead to a decrease in absolute values in difference by 50% that would reduce water demand by 11.5%.

For simplification, we consider changing all thresholds by the same percent. For example, given current block rate thresholds q_1 = 5,000 gallons, q_2 = 5,000 gallons, and q_3=10,000 gallons, we would have new thresholds of 2,500, 2,500 and 5,000 gallons (cumulative new thresholds are 2,500, 5,000 and 7,500 gallons)[10]. A more complex model, with limitations, could be developed for manipulating both block price and thresholds using difference; however, this is beyond the scope of this paper.

Conclusions and Further Research

Our model uses water use data disaggregated to the household and billing period level that covers a five-year period for Las Vegas area residential customers. The data exhibit large variation over households and time to allow us to consider the effect of price and non-price policy instruments on household water demand, as well as how exogenous factors influence these effects. A random effects specification with instrumental variables controls for correlations between time invariant household characteristics and factors that change with time, as well as solving the price/water use endogeneity problem. The model includes a wide representation of various exogenous as well as policy impacts, allowing for simulations of multiple effects of changes in these drivers of water demand. The model directly evaluates a turf removal voluntary conservation program through household-level variables that quantify square footage devoted to turf and trees.

The methods introduced in this paper demonstrate the use of estimated model and data for policy planning and evaluation, and projection of water demand. For example, we demonstrate how price increases could offset effects of increased temperature on increased water demand. We also work with properties of different elasticities of variables that can be influenced by policy (price and amount of turf), and these effects on subgroups of residential water customers. An important contribution of this study is to demonstrate how information available to water utilities can be used in econometric model of water demand to predict effects on water demand of individual and multiple demand management tools. Additionally, this study provides estimates of elasticities of demand that incorporate landscape vegetation and weather variables that could be used in other studies for arid regions of the U.S. west.

References

Agthe, D.E., R.B. Billings, J.L. Dobra, and K. Raffiee. 1986. “A Simultaneous Demand Model for Block Rates.” *Water Resources Research* 22 (1): 1-4.

Agthe, D.E. and R.B. Billings. 1987. “Equity, price elasticity, and household income under increasing block rates for water.” *American Journal of Economics and Sociology* 46: 273-286.

Al-Qunaibet, M.H. and R.S. Johnston. 1985. “Municipal Demand for Water in Kuwait: Methodological Issues and Empirical Results.” *Water Resources Research* 21 (4): 433-438.

Arbues F., M. A. Garcia-Valinas, R. Martinez-Espineira. 2003. “Estimation of Residential Water Demand: a State-of-the-art Review.” *Journal of Socio-Economics* 32: 81-102.

Arbues F., R. Barberan, I. Villanua. 2004. “Price Impact on urban Residential Water Demand: A Dynamic Panel Data Approach.” *Water Resources Research* 40(11) W11402, doi:10.1029/2004WR003092.

Arbues F., I. Villanua, and R. Barberan. 2010. “Household Size and Residential Water Demand: an Empirical Approach.” *The Australian journal of Agricultural and Resource Economics* 54: 61-80.

Balling, Robert C., and H. C. Cubaque. 2009. "Estimating future residential water consumption in Phoenix, Arizona based on simulated changes in climate." *Physical Geography* 30.4: 308-323.

Baltagi B. 1995. *Econometric Analysis of Panel Data*, New York: Wiley.

Bamezai, A.1997. "On weather normalizing customer-level billing data." *Water Resources Research* 33.5: 1171-1178.

Billings, R.B. and D.E. Agthe. 1980. “Price Elasticities for Water: A Case of Increasing Block Rates.” *Land Economics* 56 (1): 73-84.

Blundell, R., S. Bond, , M. Devereux, and F. Schiantarelli. 1992. Investment and Tobin’s *Q*: evidence from company panel data, *Journal of Econometrics* 51, 233–257.

Brandt, J. 2008. “Locating turf and water features in the Las Vegas valley, Nevada, using remote sensing techniques and GIS.” *American Society for Photogrammetry and Remote Sensing*.

Campbell, H. E., R. M. Johnson, and E. H. Larson. 2004. “Prices, Devices, People, or Rules: The Relative Effectiveness of Policy Instruments in Water Conservation.” *Review of Policy Research*, 21(5).

Castledine, K. Moeltner, M.K. Price, S. Stoddard. 2014. “Free to Choose: Promoting Conservation by Relaxing Outdoor Watering Restrictions.” *Journal of Economic Behavior & Organization*, forthcoming.

Cooley, H., T. Hutchins-Cabibi, M. Cohen, P. H. Gleick, and M. Heberger. 2007. “Hidden Oasis: Water Conservation and Efficiency in Las Vegas.” Oakland, Calif.: Pacific Institute. www.pacinst.org/reports/las_vegas.

Dalhuisen, J.M., R.J.G.M. Florax, H.L.F. de Groot, and P. Nijkamp. 2003. “Price and Income Elasticities of Residential Water Demand: A Meta-Analysis.” *Land Economics* 79 (2): 292-308.

Danielson, L. E. 1979. "An analysis of residential demand for water using micro time-series data." *Water Resources Research* 15.4: 763-767.

Deller, S.C., D.L Chicoine, and G. Ramamurthy. 1986. “Instrumental Variables Approach to Rural Water Service Demand.” *Southern Economic Journal* 53 (2): 333-346.

Foster, H.S. and B.R. Beattie. 1979. “Urban Residential Demand for Water in the United States.” *Land Economics* 55 (1): 43-58.

Fox, C., B. Mcintosh, and P. Jeffrey. 2009. “Classifying households for water demand forecasting using physical property characteristics”. *Land Use Policy*, 26, 558-568.

Gaudin, S., R. C. Griffin, and R. C. Sickles. 2001. "Demand specification for municipal water management: evaluation of the Stone-Geary form." *Land Economics* 77.3: 399-422.

Griffin, R. C, and C. Chang. 1990. "Pretest analyses of water demand in thirty communities." *Water Resources Research* 26.10: 2251-2255.

Hanke, S.H. and L. de Maré. 1982. “Residential Water Demand: A Pooled, Time Series, Cross Section Study of Malmö, Sweden.” *Water Resources Bulletin* 18 (4): 621-625.

Harlana, S. L., S. T. Yabikub, L. Larsenc, and A. J. Brazeld. 2009. “Household Water Consumption in an Arid City: Affluence, Affordance, and Attitudes, Society & Natural Resources.” *An International Journal* 22 (8): 691-709.

Hilaire, R. S., A. A. Michael, D. C. Wilkerson, D. A. Devitt, B.H. Hurd, B. J. Lesikar, V. I. Lohr, C. A. Martin, G. V. McDonald, R. L. Morris, D. R. Pittenger, D. A. Shaw, D. F. Zoldoske. 2008. “Efficient Water Use in Residential Urban Landscapes.” *HortScience* 43(7):2081–2092.

Hewitt, J.A. and W.M. Hanemann. 1995. “A Discrete/Continuous Choice Approach to Residential Water Demand under Block Rate Pricing.” *Land Economics* 71 (2): 173-192.

Höglund, L. 1999. “Household demand for water use in Sweden with implications of a potential tax on water use.” *Water Resources Research* 35 (12): 3853-3863.

House-Peters, L.A., and H. Chang. 2011. “Urban Water Demand Modeling: Review of Concepts, Methods, and Organizing principles.” *Water Resources Research* 47, W05401, doi: 10.1029/2010WR009624.

Howe, C.W. and F.P. Linaweaver, Jr. 1967. “The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure.” *Water Resources Research* 3 (1): 13-32.

Hutchins-Cabibi T., B. Miller, and A. Schwartz. 2006. “Water in the Urban Southwest: An Updated Analysis of Water use in Albuquerque, Las Vegas Valley, and Tucson.” Western Resource Advocates, www. westernresourceadvocates.org.

Jones, C.V. and J.R. Morris. 1984. “Instrumental Price Estimates and Residential Water Demand.” *Water Resources Research* 20 (2): 197-202.

Kenney, D.S., C.Goemans, R. Klein, J. Lowrey, and K. Reidy. 2008. “Residential Water Demand Management: Lessons from Aurora, Colorado.” *Journal of the American Water Resources Association* 44(1): 192-207.

Lyman, R. A. 1992. "Peak and off-peak residential water demand." *Water Resources Research* 28.9: 2159-2167.

Michelsen, A.M., J.T. McGuckin, and D. Stumpf, 1999. “Nonprice Water Conservation Programs as a Demand Management Tool.” *Journal of the American Water Resources Association* 35(3):593-602.

Maidment, D. R., and Shaw-Pin Miaou. 1986. "Daily water use in nine cities." *Water Resources Research* 22.6: 845-851.

Martinez-Espineira, R. 2002. "Residential water demand in the northwest of Spain." *Environmental and Resource Economics* 21.2: 161-187.

Miaou, Shaw-Pin. 1990. "A class of time series urban water demand models with nonlinear climatic effects." *Water Resources Research* 26.2: 169-178.

Moelter, K. and S. Stoddard. 2004. “A panel data analysis of commercial customers’ water price responsiveness under block rates.” *Water Resources Research* 40, W01401, doi:10.1029/2003WR002192.

Nauges C, and A. Thomas. 2000. "Privately Operated Water Utilities, Municipal Price Negotiation, and Estimation of Residential Water Demand: The Case of France." *Land Economics* 76.1.

Nauges C, and A. Thomas. 2003. Long-run Study of Residential Water Consumption.” *Environmental and Resource Economics* 26: 25-43.

Nieswiadomy, M.L. and D.J. Molina. 1988. "Urban water demand estimates under increasing block rates." *Growth and Change* 19.1: 1-12.

Nieswiadomy, M.L. and D.J. Molina. 1989. “Urban Water Demand Estimates Under Decreasing and Increasing Block Rates Using Household Data.” *Land Economics* 65 (3): 280-289.

Nordin, J.A. 1976. “A proposed modification of Taylor’s demand analysis: comment.” *The Bell Journal of Economics* 7 (2): 719-721.

Olmstead, S. M., W. M. Hanemann, and R. N. Stavins. 2007. "Water demand under alternative price structures." *Journal of Environmental Economics and Management* 54.2: 181-198.

Pint, E. M. 1999. "Household Responses to Increased Water Rates During the California Drought." *Land economics* 75.2.

Polebitski, A.S. and R.N. Palmer. 2010. “Seasonal Residential Water Demand Forecasting for Census Tracts.” *Journal of Water Resources Planning and Management* 136 (1): 27-36.

Polebitski, A.S., R. N. Palmer, and P. Waddell. 2010. "Evaluating water demands under climate change and transitions in the urban environment." *Journal of Water Resources Planning and Management* 137.3: 249-257.

Renwick, M.E. and S.O. Archibald. 1998. “Demand Side Management Policies for Residential Water Use: Who Bears the Conservation Burden?” *Land Economics* 74 (3): 343-359.

Saleth R. M. and A. Dinar. 2000. “Institutional changes in global water sector: trends, patterns, and implications”, *Water* Policy 2(3): 175–199.

Schefter J. E. and E. L. David. 1985. “Estimating Residential Water Demand under Multi-Part Tariffs Using Aggregate Data”. *Land Economics* 61 (3): 272-280.

Southern Nevada Water Authority. Water Resource Plan 2009. http://www.snwa.com/assets/pdf/wr_plan.pdf

Southern Nevada Water Authority. Conservation Plan 2009-2013. http://www.snwa.com/assets/pdf/about_reports_conservation_plan.pdf

Sovocool K. A., and M. Morgan. 2006. " Xeriscape Conversion Study." Final Report. Southern Nevada Water Authority.

Sovocool K. A., M. Morgan, and D. Bennett. 2006. "An in-depth investigation of Xeriscape as a water conservation measure." American Water Works Association 98 (2): 82-93.

Syme, G. J., B. E. Nancarrow, and C. Seligman, 2000. The Evaluation of Information Campaigns to Promote Voluntary Household Water Conservation. *Evaluation Review* 24(6):539-578.

Taylor, L.D. 1975. "The Demand for Electricity: A Survey." *The Bell Journal of Economics* 6 (1): 74-110.

United States Census Bureau. Clark County Nevada. http://quickfacts.census.gov/qfd/states/32/32003.html

Wentz E.A., and P. Gober. 2007. "Determinants of small-area water consumption for the city of Phoenix, Arizona", *Water Resour. Manage.*, 1849-1863, doi: 10.1007/s11269-006-9133-0.

Worthington, A.C. and M. Hoffman. 2008. "An Empirical Survey of Residential Water Demand Modelling." *Journal of Economic Surveys* 22 (5): 842-871.

Tables and Figures

Table 1. Variable Description

Variable	Definition	Units	Level of Disaggregation
y	Household consumption per billing period	1,000 Gallons	household and time
AvgTemp	Avg daily temperature for billing period	F	household and billing period
Days of Precipitation	Days of precipitation in billing period	# of days	household and billing period
AvgWindSpeed	Average daily wind speed over billing period	Knots	household and billing period
Period variables	59 dummy variables = 1 for each month / year	0-1	household and month
Number of Bedrooms	# of Bedrooms, a proxy for family size	# bedrooms	household
Income/Wealth	Monthly income derived from assessed property value	2007 $	household
Pool presence	Dummy variable = 1 if a pool on property	0-1	household
Marginal Price	CPI adjusted marginal price	2007 $	household and month
Difference	CPI adjusted difference	2007 $	household and month
Days on bill	Days in monthly bill	# of days	household and month
Size of Turf	Area of property covered by turf	Sq. Ft.	household and month
Size of Trees	Area of property in trees and shrubs	Sq. Ft.	household and month
Non-irrigated area	Calculated as difference between area of yard and area of turf and trees	Sq. Ft.	household and month
Turf Restrictions	Restriction on turf size on properties constructed after 2003	0-1	by household and month

Table 2. Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max	Med
Beds number	3.37	0.80	1	11	3
Income	3229	1763	298	32338	2973
Days in bill	30.4	2.0	23	38	30
Water use quantity	12.00	8.57	1	94	10
Marginal price	2.31	0.89	1.10	4.52	2.1
Avg temperature	70.6	16.37	43	98	69
Days of precipitation	2.01	2.04	0	13	2
Avg wind speed	6.79	1.8	2.9	11.3	6.4
Turf size	202	372	0	8115	16
Trees size	1347	1085	0	15361	1095
Non irrigated area	3593	2227	0	70780	3147

Table 3. Second Stage Regression Coefficient Estimates

Variables	Coefficient	Std. Error
Difference	-0.0215	0.00150***
Marginal price	-0.1484	0.01234***
Days	0.0272	0.00053***
Household size	0.0919	0.00197***
Income	0.00004	1.04E-06***
Avg, Temperature	0.0086	0.00018***
Days of Precipitation	-0.0081	0.00018***
Avg, Wind speed	0.0140	0.00042***
Size of Turf	0.00029	6.68E-06***
Size of Trees	0.00013	2.55E-06***
Non-Irrigated Area	-0.00002	6.37E-06***
Pool	0.0595	0.00187***
Turf Restriction Policy	-0.0896	0.00374***
Constant	0.1652	0.04673*

R-sq overall = 0.4684

*** Significance level of 1%, ** 5%, and * 10%

Table 4. Average Elasticities of Demand for Selected Explanatory Variables

Variable	Elasticity for mean	Elasticity for median	Variable	Elasticity for mean	Elasticity for median
Marginal price	-0.343	-0.312	**Income**	0.129	0.119
Family size	0.310	0.276	**Avg Temperature**	0.610	0.596
Size of Turf	0.058	0.005	**Days of Precipitation**	-0.016	-0.016
Size of Trees	0.169	0.138	**Avg Wind speed**	0.095	0.089

Table 5. Water Demand. 20 year Projections with Increases in Temperature and Price

Variable	Increase by 1 F over 20 years			Increase by 2 F over 20 years	
	Gallons per household	Acre feet per population*		Gallons per household	Acre feet per population*
Temperature	12,521	6,178		25,114	12,397
Temperature (min)	12,259	6,049		24,588	12,137
Temperature (max)	12,783	6,307		25,641	12,656

	Increase by $0.1			Increase by $0.5	
	Gallons per household	Acre feet per population*		Gallons per household	Acre feet per population*
Price	(42,722)	(21,079)		(213,612)	(105,441)
Price (min)	(46,275)	(22,832)		(231,377)	(114,210)
Price (max)	(39,170)	(19,326)		(195,848)	(96,672)

* This is a proxy for single households that calculated as the number of house units multiplied by 66% and equal to 160,843 households. The source is US Census Bureau for Las Vegas in 2010

Table 6. Analysis of Elasticities of Policy Variables: Price and Turf Size

			1st Portfolio (20% of Price			2nd portfolio (30% Price		
Percentiles of explanatory variables	**Price, $**	**Turf, sf**	20% price increase	30% turf decrease	**Sum of water decrease, %**	30% price increase	20% turf decrease	**Sum of water decrease, %**
Min	1.1	0	3.3 %	0.0 %	3.3 %	4.9 %	0.0 %	4.9 %
10%	1.18	0	3.5 %	0.0 %	3.5 %	5.3 %	0.0 %	5.3 %
25%	1.91	0	5.7 %	0.0 %	5.7 %	8.5 %	0.0 %	8.5 %
50% (Median)	2.1	20	6.2 %	0.2 %	6.4 %	9.3 %	0.1 %	9.5 %
Mean	2.31	202	6.9 %	1.7 %	8.6 %	10.3 %	1.2 %	11.4 %
75%	2.99	249	8.9 %	2.1 %	11.0 %	13.3 %	1.4 %	14.7 %
90%	3.1	643	9.2 %	5.5 %	14.7 %	13.8 %	3.7 %	17.5 %
Max	4.52	8115	13.4 %	69.6 %	83.0 %	20.1 %	46.4 %	66.5 %
Regression coefficients	-0.1484	0.00029		Average, %	17.02 %		Average, %	17.29 %

Figure 1. Plot of Period Dummy Variables

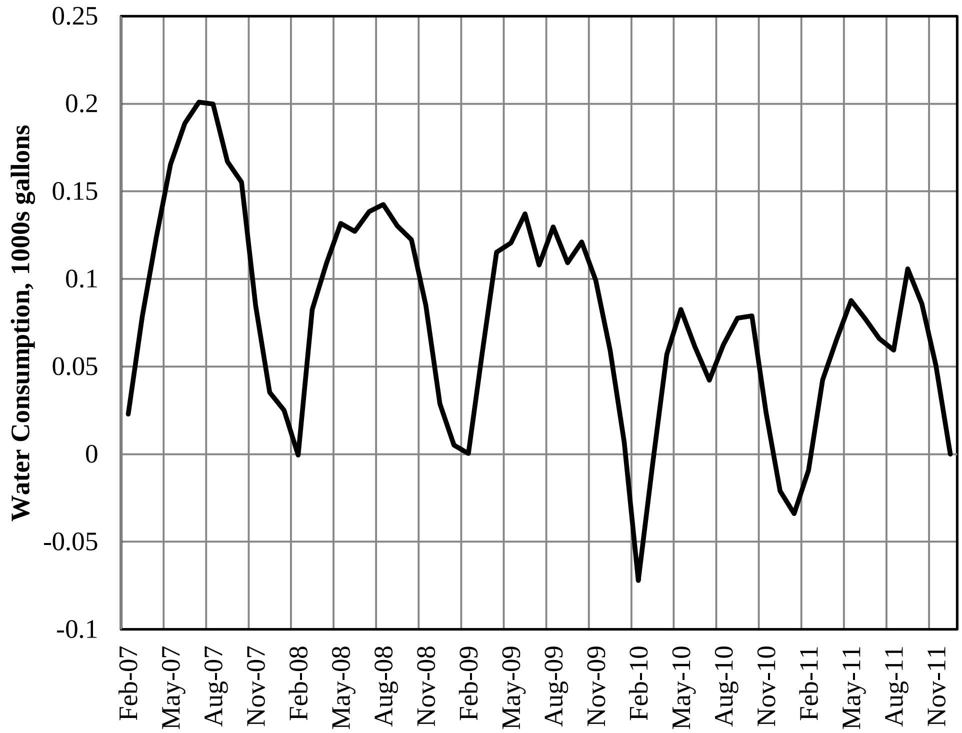


Figure 2. Percentage of Water Savings Depending on Initial Size of Turf and Size of Replaced Trees

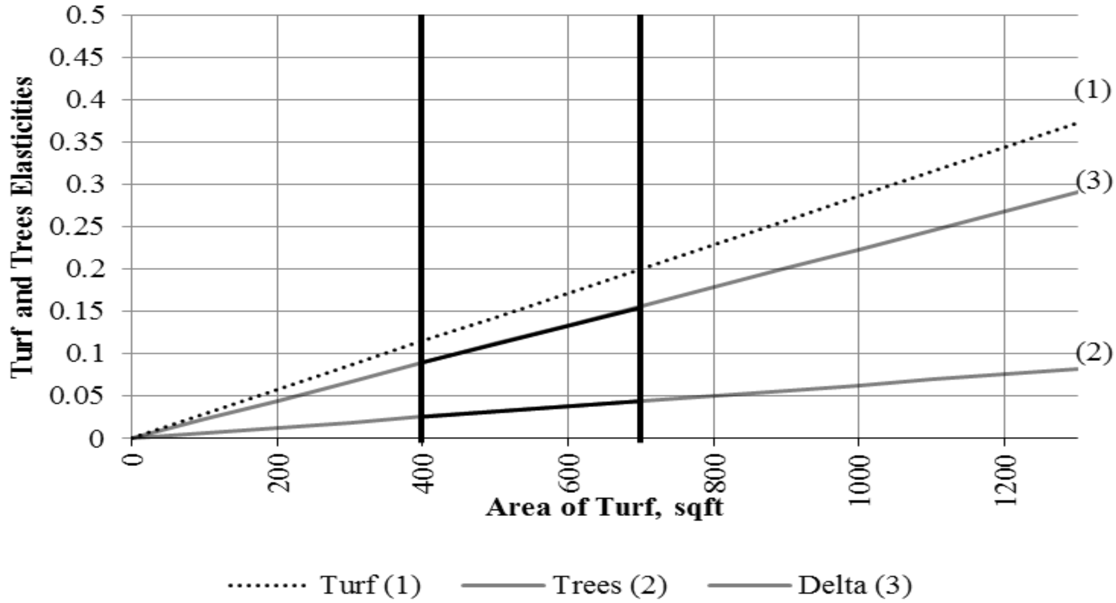


Figure 3. Percentage of Households by Elasticities of Water Demand in Respect to Turf.

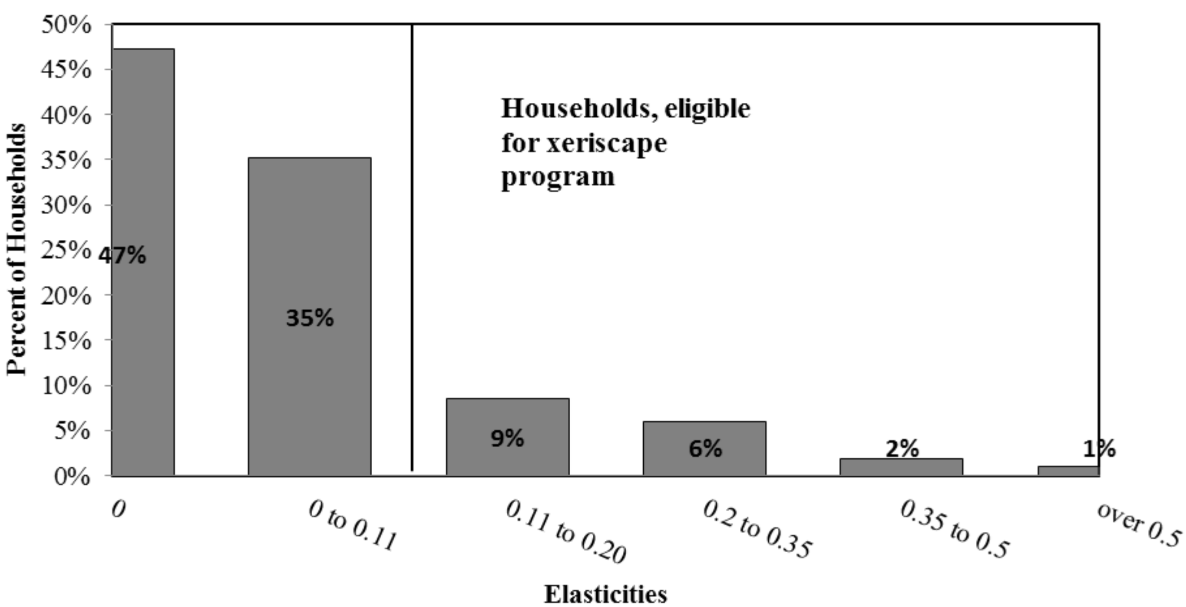
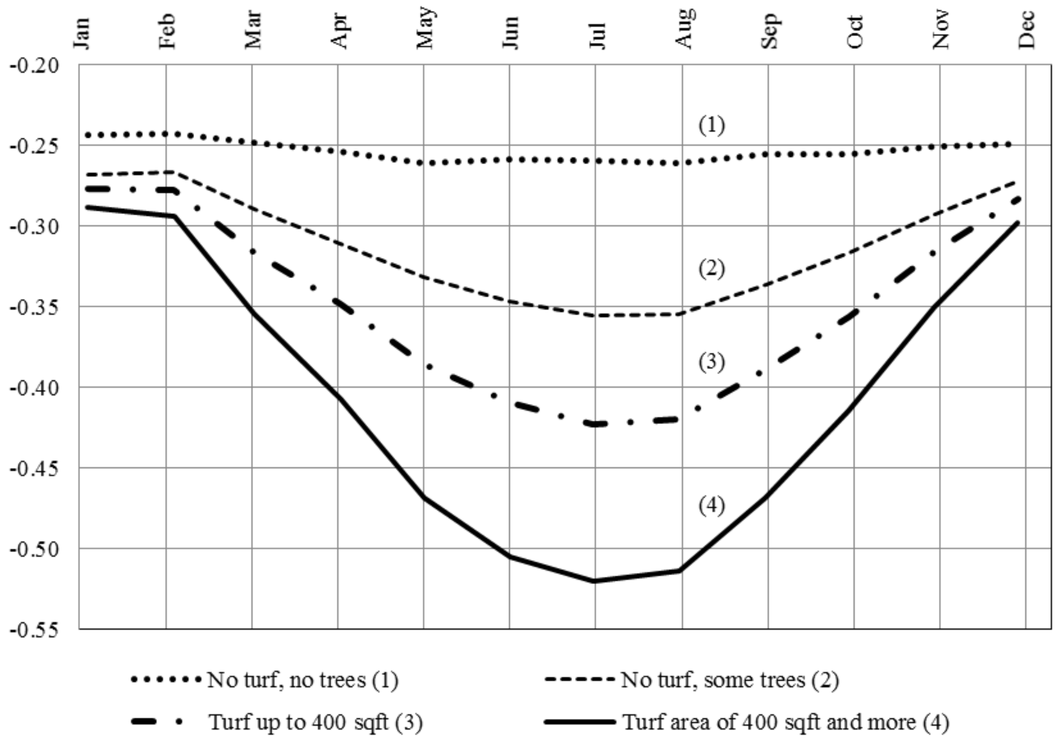


Figure 4. Water Demand Elasticities in Respect to Marginal Price by Monthly Means



Footnotes

---

[1] For example, in the region served by the Truckee Meadows Water Authority, which includes the cities of Reno and Sparks in Northern Nevada, winter water consumption is approximately 30 million gallons per day (MGD), while summer peak use is approximately 120 MGD. The difference is largely due to irrigation. Similarly, outdoor consumptive use accounts for 70% of residential water demand in the Las Vegas area (Cooley et. al. 2007).

[2] Additionally, irrigation use of water can pose a larger strain on limited water resources because it does not recirculate back into water supplies easily accessible by water utilities.

[3] Michelsen et al. (1999) and Syme et al. (2000) show modest short-run benefits from public education programs, while Kenney et al. (2008) claim that quantitative analysis of education programs remains a challenge.

[4] The difference variable, introduced by Nordin (1976), is the difference between the total bill and what the household would pay if the total quantity of water consumed was charged at the marginal price.

[5] Polebitski et al. (2010) and Balling and Cubaque (2009) use forecasts from downscaled Global Climate Models to estimate the effect of climate change on urban water demand. Both studies build on estimated water demand models using bimonthly (Polebitski and Palmer) or monthly (Balling and Cubaque) billing data aggregated at the census tract level. Our disaggregated data allows a behavioral model of heterogeneous residential water consumers' landscape irrigation decisions under varying weather conditions.

[6] Calculation of the elasticities for each observation of an independent variable: by elasticity definition $\varepsilon = (dy/y)/(d\,x/x) = (dy/dx)(x/y) = slope*(y/x) = b*y*(x/y) = b*x$. Where slope $dy/dx = b*exp(a+bx)$, b is the slope, and a is the intercept for a linear specification.

[7] Howe and Linaweaver (1967) and Danielson (1979) decomposed residential water demand into indoor and outdoor components and separated elasticities by summer and winter seasons. Hewitt and Hanemann (1995) and Olmstead *et. al*. (2007) calculated separate price elasticities in the context of a block rate pricing structure, but their work did not focus on using these to project outcomes of policy implementation.

[8] SNWA's "50 Percent Living Plant Requirement" states that converted areas must contain enough plants to create at least 50 percent living plant cover at maturity (www.snwa.com).

[9] $d_n = q_1r_1 + q_2r_2 + \ldots + q_nr_n - q_1mp - q_2mp - \ldots - q_nmp$. Since in the last nth block, *mp* equals to r_n, equation components with q_n go away and $d_n = q_1r_1 + q_2r_2 + \ldots + q_{n-1}r_{n-1} - q_1mp - q_2mp - \ldots - q_{n-1}mp) = q_1 (r_1-mp) + q_2(r_2-mp) + \ldots + q_{n-1}(r_{n-1}-mp)$.

[10] It is possible to hold constant one block while manipulating the other block ranges. For this, additional limitations should be implied depending on the policy targets.