The Effect of Price and Non-Price Conservation Programs on Residential Water Demand

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Abstract. The study examines effectiveness of price- and non-price residential water demand management programs. Household-level water use data for Alachua County, Florida, were analyzed using three methods: IV, 2SLS, and 3SLS. Residential water demand is examined separately for households with combined water meters, as well as separate indoor and outdoor irrigation water meters. Preliminary results show that the price-base program (i.e., inclining block rate pricing) and non-price programs (i.e., residential irrigation restrictions with an enforcement component) have a significant effect on monthly household water use.

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Introduction

Nationwide, 44.2 billion gallons of freshwater per day is withdrawn for public water supply, with California, Florida, New York, and Texas accounting for 37 percent of this volume (Kenney et al. 2009). Residential water conservation is one of the primary strategies to cope with the challenge of meeting water demands given continuous population growth, limited freshwater resources, lack of opportunities for water transfers among water use sectors (such transfers between agriculture and urban sectors), and potential impacts of climate change (Ozan and Alsharif 2013, Olmstead and Stavins 2007). To encourage water conservation, state and local agencies and water utility companies use a variety of price-based water demand management strategies, including inclining block pricing schemes (i.e., increasing per-unit water prices depending on water use volumes). Non-price demand management programs are also used widely, including residential irrigation restrictions, toilet replacement programs, and outreach programs. Existing economic studies have examined reduction in residential water use given inclining block pricing schemes implemented simultaneously with non-price programs. However, the appropriate methodology for modelling residential water demand and estimating the effectiveness of price and non-price demand management programs are still in discussion. In this paper, we use panel dataset of household-level water use in Alachua County, Florida, and examine effectiveness of two demand management programs: inclining block price structure (i.e., price-based program) and residential irrigation restrictions with an inspection component (i.e., non-price program). Implications for selecting a mix of residential water demand management programs by local agencies are discussed.

Residential Water Demand Management

Population, household and property characteristics, climatic factors, and price and non-price demand management programs implemented by government agencies are the principal factors influencing residential water demand (Young, 1973, Olmstead et. al. 2007, House-Peters and Chang, 2011). The nature of water suggests that there is no substitute for it. However, residential water use categories can still be classified into non-discretionary (mostly indoor water use, such as drinking and sanitation) and discretionary (most of the outdoor water use, such as residential irrigation). In California, Florida, Texas, and other western and southern states with hot climates, residential irrigation accounts for one third to one half of the total residential water use (Hermitte, 2012; Friedman *et al.*, 2013; Southwest Florida Water Management District, undated; Arizona Department of Water Resources, 2014). Government agencies and water utility companies employ both price- and non-price programs to encourage reduction in discretionary residential irrigation (Billing and Agthe, 1980).

Olmstead and Stavins (2007) show that for a specific water conservation goal, price-based programs (i.e., increase in price) are generally more cost-effective than non-price programs (such as restrictions on water use). Price-based strategies allow households the freedom to decide what changes to make in response to price increases. Households can use their privately-held information to make the least-cost adjustments in response to price change, minimizing their private costs of water use reduction. In addition, price-based programs allow for least-cost re-allocation of water among households, when households with lower value for water cut their water use to a greater extent than the households with higher value for water. Price-based program also encourage water conservation without jeopardizing revenue collection goals for utility companies. Note that the effect of a price-based program depends on the slope of the water demand function, and the slope in turn depends on the household characteristics, seasonal weather conditions, and other factors. Given that state agencies and utility companies usually have limited information about household water demand functions, they may not be able to accurately predict the change in the water use in response to price-based strategies.

In contrast to price-based programs, non-price programs directly limit specific residential water use categories. For example, agencies and utility companies around US rely on irrigation restrictions that limit the number of days per week (and/or the hours during a day) when residential irrigation is allowed. Such programs leave households limited freedom to choose what low-value activities to give up to conserve water. In addition, since agencies and utility companies have limited information about household-specific water demands, the same limits on water use are usually set for all households. Such uniform limits impose high costs on the households that value highly the activities requiring residential irrigation. In contrast, the households with low values for such activities can give up more water use than it is required by the restrictions, and they can do that at low costs. In other words, such programs restrict re-allocation of water among activities within the households, as well as reallocation of water among the households, increasing the total costs of water conservation. In theory, an advantage of water use restrictions is the ability for the agencies and water utilities to predict water use reductions. However, in practice, the restriction programs often lack monitoring and enforcement component, and hence, the water use levels and the water conservation resulting from the programs remain uncertain (Olmstead and Stavins 2007).

The effects on water use of price-based and non-price demand management programs are illustrated on figure 1. Initial levels of water use for the two households is denoted by Q_1. Since households 1 have less elastic demand, the change in price from P_1 to P_2 does not induce significant water use reductions for that household (as compared with household 2). Such price-based program will result in reduction in total water use by ΔQ (where $\Delta Q = \left(Q_1^{household\ 1} + Q_1^{household\ 2}\right) - \left(Q_2^{household\ 1} + Q_2^{household\ 2}\right)$). Although households use different volumes of water, their marginal value of water is the same and equal to the price.

Alternatively the same water conservation target ΔQ can be achieved by requiring both households to reduce water use to the same level Q_3 (e.g., by imposing irrigation restrictions). Resulting marginal value of water for household 1 will be higher than that for household 2 (compare Λ_1 and Λ_2), and hence, the households would be better off by “trading” water allocations between each other (Olmstead and Stavins, 2007).

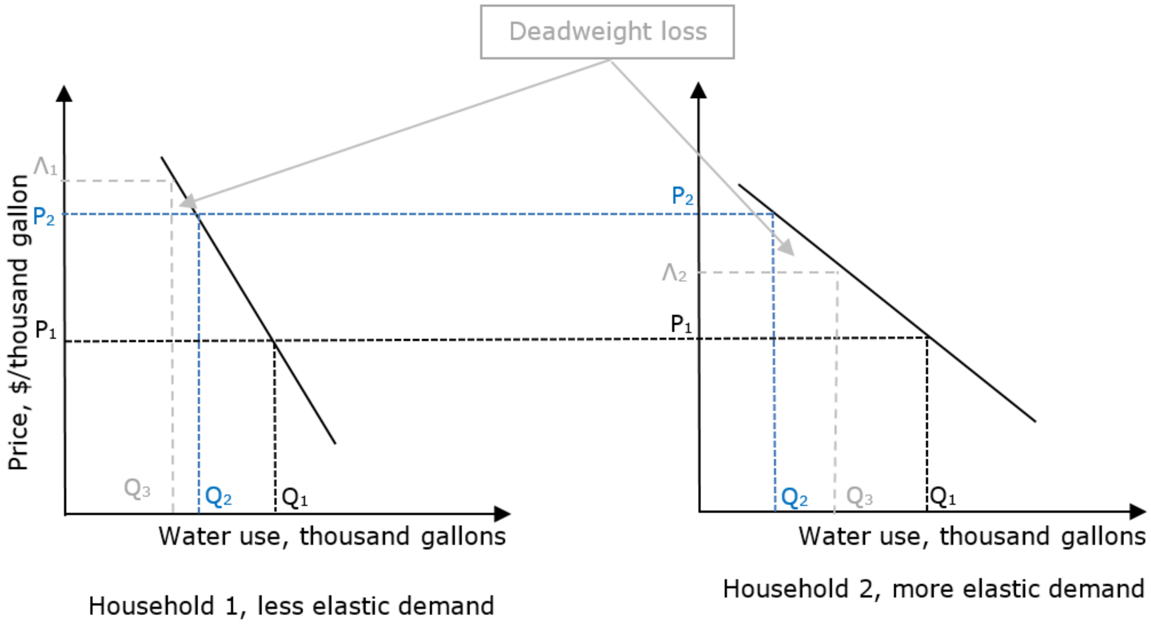

Figure 1. Price- and Non-Price Water Demand Management Programs (Source: modified from Olmstead and Stavins, 2007)

Residential Water Demand Models

In the example above, the changes in the water use in response to price increase, as well as the reduction in consumer surplus for price-based and non-price programs, depends on the slope of the household demand functions. Over the past decades, economists argued about the best way to estimate the water demand as a function of price and other determinants. Water demand is generally represented as an ad-hoc function where the quantity of water used is influenced by the water price, weather variables, and household characteristics:

$$Q = f(P, Z) \tag{1}$$

In this equation, Q represents water use per household; P is price variable(s), and Z represents a vector of other variables that influences water use (such as weather effects, various household characteristics, and/or non-price demand management programs).

In early water demand studies conducted in 1970s, Ordinary Least Square method was used to estimate the parameters in water demand function (1). Under a uniform price (i.e., a price structure with a constant per-unit water price), researchers estimated water use as a function of average prices and rainfall (inches) given time series data of aggregate water use (Young, 1973), or as a function of average prices, rainfall, and household characteristics for cross-sectional data. For instance, Foster and Beattie (1979) set the function as $Q = f(P, Y, R, N)$, where Q is the quantity of water demanded per household, P is average water price per cubic feet, Y is median household income, R is the precipitation in inches, and N is average number of residents per meter of living area in a house. Under block rate pricing (with inclining per-unit water prices), Taylor (1975) proposed to include both marginal and average prices as explanatory variables. In turn, Nordin (1976) proposed to include a difference variable instead of average prices. The difference variable (also referred to as "rate structure premium") is defined as the total bill minus the product of marginal price and total water use. The difference variable was proposed to eliminate the upward bias in price elasticity estimates based on the marginal price only.

Although early water demand elasticity estimates that relied on OLS were lately criticized for biased results (attributed to the endogeneity of price variables given increasing block pricing), these elasticity estimates still provide a baseline for the later studies. The meta-analysis of early water demand analysis showed the price elasticities from -1.24 to 0.01 (and income elasticities from 0.00 to 1.03) (Wong 1972).

The studies conducted in 1980s and 1990s extensively used panel data and instrumental variable (IV) technique, which was first applied to the water demand analysis by Agthe and Billing (1986a; 1986b) and Nieswiadomy and Molina (1989). Specifically, Agthe and Billing (1986) introduced IV procedure to the demand model specified as $Q = f(MP, RP, W, Y)$ where Q is average household monthly water consumption; MP marginal price in cents; RP rate structure premium; W evapotranspiration minus rainfall in inches; Y personal income per household in the study area in dollars per time period. Instrumental variables for RP and MP include the lagged values of all endogenous and exogenous variables in the system. All price and income variables were adjusted for inflation using Consumer Price Index. This method was further improved by using different IVs and 2- and 3-stage least squares techniques (Nieswiadomy and Molina 1991; Dalhuisan et al. 2003).

An alternative method for modeling water demand decision under inclining block pricing was introduced by Hewitt and Hanemann (1995) and Pint (1999). Researchers argued that consumers face a two-stage choice: first, the customers choose the price block for water use, and then they choose the quantity of water consumed within the block. To model such choices, the researchers introduced discrete choice (D/C) model that uses logarithmic demand function

$$\ln Q = Z\delta + \alpha \ln p + \gamma \ln y + \eta + \varepsilon \tag{2}$$

where $\ln Q$ is the natural logarithm of the household water use, p is the marginal price and y is income and Z includes weather, water supplier fixed effects and household characteristics. The error terms, η and ε, represent heterogeneous water use preferences among households and random error both from the household characteristics and demand model structure. Although modelling water use decisions as a two-stage choice has an appeal, the price elasticities estimated by Hewitt and Hanemann (1995) and Pint (1999) were high in absolute values (from -1.4 to -1.6 in Hewitt and Hanemann (1995), and from -0.04 to -1.25 in Pint (1999)) .

Olmsted, Hanemann and Stavins (2007) suggested using piecewise-linear budget constraints in D/C model when detailed individual level data are available, and they found a lower price elasticity of around -0.60. For the consumer faced with increasing block pricing, conditional demand for the *k*th price block becomes the following:

$$\ln q = \begin{cases} \ln q_1^*(Z, p_1, \tilde{y}_1; \delta, \alpha, \gamma) + \eta + \varepsilon \\ if\ -\infty < \eta < \ln q_1 - \ln q_1^*(Z, p_1, \tilde{y}_1; \delta, \alpha, \gamma) \\ \\ \ln q_1 + \varepsilon \\ if\ \ln q_1 - \ln q_1^*(Z, p_1, \tilde{y}_1; \delta, \alpha, \gamma) < \eta < \ln q_1 - \ln q_2^*(Z, p_2, \tilde{y}_2; \delta, \alpha, \gamma) \\ \\ \cdots \\ \\ \ln q_{K-1} + \varepsilon \\ if\ \ln q_{K-1} - \ln q_{K-1}^*(Z, p_{K-1}, \tilde{y}_{K-1}; \delta, \alpha, \gamma) < \eta < \ln q_{K-1} - \ln q_K^*(Z, p_K, \tilde{y}_K; \delta, \alpha, \gamma) \\ \\ \ln q_K^*(Z, p_K, \tilde{y}_K; \delta, \alpha, \gamma) + \eta + \varepsilon \\ if\ \ln q_{K-1} - \ln q_K^*(Z, p_K, \tilde{y}_K; \delta, \alpha, \gamma) < \eta < \infty \end{cases} \tag{3}$$

where each price block is depicted by p_k, optimal consumption on block k is $\ln q_k^*(Z, p_k, \tilde{y}_k; \delta, \alpha, \gamma)$, log of consumption on the kink k is $\ln q_k$, and δ, α and γ are parameters to be estimated. Moreover, new income variable, $\tilde{y}_k$, can be calculated based on the block the consumer is on and using the following difference term:

$$d_k = \begin{cases} 0 & if\ k = 1 \\ \sum_{j=1}^{k-1} (p_{j+1} - p_j) q_k & if\ k > 1 \end{cases} \tag{4}$$

and $\tilde{y}_k = y + d_k$ is the income plus the difference term. An advantage of this model is the ability to estimate both conditional elasticities for a particular consumption block choice (using a simultaneous equations model) and unconditional elasticities for the consumption on any block (using a maximum likelihood method). This method also allows modeling responses to demand shocks due to significant price increases for high water use levels, since the choice of consumption on high price blocks is modeled explicitly for high water users. However, D/C method requires water use observations given a wide range of prices, and hence it is not appropriate for modeling water demand of the households served by a single water provider and given relatively narrow range of (or constant) prices. The D/C model is also based on the assumption that households are aware of pricing structure, and that assumption may not always reflect the reality.

Estimation of water demand using difference-in-difference methodology was recently introduced by Nataraj and Hanemann (2011). Lately, Klaiber et al (2012) suggested a new modification of the difference-in-difference method for the case with limited household information, inclining block pricing structure, and the change in price structure such that the prices increase at the same proportion for each price block. If water demand is specified as a function of price, household characteristics, and weather, then the difference model allows eliminating household characteristics, and finding the price effect using the resulting intercept. The researchers propose to take the difference between two years, and focus on the years when the water supplier changes the price structure. In mathematical term, water demand can be represented as follows:

$$q_{ijt} = \alpha_0 + \alpha_1 p_{jtb} + f(z_i) + g(T_{jt}) + u_{ijt} \qquad (5)$$

where q_{ijt} is the water consumed by household *i* in the month *j* of year *t*. The price is represented by the marginal price faced by each household, p_{jtb} for the *k*th block in the month *j* of the year *t*. The household characteristics are reflected in $f(z_i)$; the weather effect is $g(T_{jt})$; and the error term is u_{ijt}.

The difference model eliminates the intercept term (α_0) and the household characteristics ($f(z_i)$). Since it is assumed that the prices increase at the same proportion for each price block, the intercept α_1 represents the price effect and it is expected to have negative sign to comply with the theory:

$$q_{ijt+a} - q_{ijt} = \alpha_1 + (g(T_{jt+a}) - g(T_{jt})) + (u_{ijt+a} - u_{ijt}) \qquad (6)$$

The price elasticity of demand in this case can be calculated as

$$\eta_{price} = \frac{\alpha_1}{(p_{jtb+a} - p_{jtb})} \frac{p_{jtb+a}}{q_{ijt+a}} \quad (7)$$

Lately, Yoo et al. (2014) suggested that the model proposed by Klaiber et al. (2012) have an omitted variable bias if it is estimated using households supplied by a single water provider. The researchers added price and income differences into this model to account for the price and income effect rather than using the constant term as a proxy for price effect. The study also proposed a modification of the difference-in-difference model that included the change in prices, weather-related characteristics, and dummy variables to capture water-intensive features of residential properties (such as pool ownership and property value):

$$q_{ijt+a} - q_{ijt} = \alpha_1 + \alpha_2 \cdot (p_{jtb+a} - p_{jtb}) + (g(T_{jt+a}) - g(T_{jt})) + \alpha_p \cdot D_{pool} + \alpha_v \cdot D_{value} + (u_{ijt+a} - u_{ijt}) \quad (8)$$

In this case, the price elasticity of demand can be calculated as

$$\eta_{price} = \alpha_2 \frac{p_{jtb+a}}{q_{ijt+a}} \quad (9)$$

Both Klaiber et al. (2012) and Yoo et al. (2014) report a wide range of price elasticities for the user groups differentiated by income levels. In Klaiber et al. (2012), price elasticities ranged from -0.13 to -1.93, and in Yoo et al. (2014), they fell between -2.40 and -0.89. Moreover, Yoo et al. (2014) calculated short run and long-run price elasticities without differentiating them by users' income levels, with the resulting range from -1.55 to -0.66. Finally, Yoo et al. (2014) also estimated income elasticity to range from 0.002 to 0.078.

Overall, a review of the residential water demand literature showed that the magnitude of price elasticity estimates varied both with the econometric techniques applied, and the type of data used (panel versus cross-section data, or aggregated versus individual-level water consumption data) (Table 1). However, we can draw two general conclusions. First, the water demand is inelastic, with most of the price elasticity estimates being from -0.30 to -0.65. Second, the long-run elasticity is larger than the short-run elasticity since consumers can substitute water with the plumbing services (i.e., repair leaky faucets), more water-efficient appliances, and drought-tolerant landscaping (Wong, 1972; Espey *et al*. 1997; Dalhuisan et al., 2003; and Arbues et al. 2003).

Table 1. Estimates of Price and Income Elasticity of Residential Water Demand

Author(s)	**Year**	**Study area**	**Type of Data**	**Methodology**	**Price Elasticity**	**Income Elasticity**
Metcalf	1926	29 water suppliers	Cross-sectional	OLS	-0.65	
Larson and Hudson, Jr.	1951	15 Illinois Communities	Cross-sectional	OLS		0.70
Hanson and Hudson, Jr.	1956	8 Illinois Communities	Cross-sectional	OLS		0.55
Seidel and Baumann	1957	497 water utilities in the United States	Cross-sectional	OLS	-0.12 to -1.0	
Fourt	1958	34 cities in US	Cross-sectional	OLS	-0.39	0.28
Renshaw	1958	36 water utilities	Cross-sectional	OLS	-0.45	
Milliman	1963	Based on assumptions	1961	OLS	-0.3 to -0.4	
Gottlieb	1963	Several utility companies in Kansas	Cross-sectional	OLS	-0.66 to --1.24	0.28 to 0.58
Wong et al.	1963	Northeastern Illinois	Cross-sectional	OLS	0.01 to -0.72	
Headley	1963	San Francisco-Oakland	Time Series 1950-59	OLS		0.00 to 0.40
Gardner and Schick	1964	43 Northern Utah Water Syst.	Cross-sectional	OLS	-0.77	
Flack	1965	54 cities in Western US	Cross-sectional	OLS	-0.12 to -1.0	
Bain et al.	1966	41 cities in California	Cross-sectional	OLS	-1.099	
Howe and Linaweaver	1967	39 study areas for 16 utilities	Cross-sectional	OLS	-0.21 to -0.23	0.31 to 0.37
Conley	1967	24 Communities in Southern California	Cross-sectional	OLS	-1.02 to -1.09	
Turnovsky	1969	19 Massachusetts Towns	Cross-sectional	OLS	-0.05 to -0.40	
Wong	1970	Chicago City	Time-series 1951-1961	OLS	-0.02 to -0.28	0.20 to 0.26
Wong	1970	Chicago, four communities	Cross-sectional	OLS	-0.26 to -0.82	0.48 to 1.03
Wong	1972	Chicago and neighboring communities	Time Series 1951-61	OLS	-0.28	0.19 to 0.26
Young	1973	Tuscon, Arizona	Time Series 1946-64 and 1965-1971	OLS - linear	-0.65 and -0.41	
Young	1973	Tuscon, Arizona	Time Series 1946-64 and 1965-1971	OLS - logarithmic	-0.60 and -0.41	
Foster and Beattie	1979	U.S. Nation-wide in six regions	Cross-sectional	OLS	-0.35 to -0.76	
Billing and Agthe	1980	Tuscon, Arizona	Time-series, 1974-1977	OLS (marginal prices)	-0.267 log model -0.45 to -0.61 linear	
Agthe and Billing	1986	Tuscon, Arizona	Time-series, 1974-1980	OLS-IV-3SLS	-0.624 LR -0.364 SR Data:1974-1977 -0.595 LR -0.265 SR	
Agthe and Billing	1986	Tuscon, Arizona	Time-series, Real Prices, 1974-1980	OLS-IV-3SLS	-0.247 LR -0.136 SR Data:1974-1977 -0.125 LR -0.019 SR	
Nieswiadomy and Molina	1989	Denton, Texas	Monthly Panel (1976-1980 decreasing block rate, 1981-1985 increasing block rate)	2SLS techniques	-0.36 to -0.55	0.15 to 0.14

Nieswiadomy and Molina	1991	Denton, Texas	Monthly Panel (1976-1980 decreasing block rate, 1981-1985 increasing block rate)	OLS and IV techniques	Test for Response to Marginal Price Changes	
Hewitt and Hanemann	1995	Denton, Texas	Monthly Panel (1981-1985 increasing block rate)	D/C Model (MLE)	-1.586 to -1.629	0.1526 to 0.1582
Pint	1999	Alameda, Newark/ Union City, California	Monthly Panel 1982-1992	D/C Model (MLE)	-0.04 to -0.29 -0.20 to -1.24	
Dahan and Nisan	2005	Jerusalem, Israel	Cross sectional 2003	OLS, 2SLS, and Maximum Likelihood	Compare Estimation Results	
Olmstead et al.	2007	11 urban areas in the United States and Canada	Panel Data	D/C Model (MLE)	-0.33 to -0.61	0.13 to 0.19
Nauges and Blundell	2001	Cyprus	Cross sectional 1997	D/C Model (MLE) Non-parametric	-0.79 to -0.24	0.08 to 0.37
Kenney et al.	2008	Aurora, Colorado 2002-2004	Panel Data	FE-IV technique	-.34 to -.75	
Miyawaki et al.	2011	Japan, 2006 – 2007	Panel data	Multinomial type V Tobit model	-0.51to -0.37	0.14 – 0.57
Klaiber et al.	2012	Phoenix, AZ 2000-2003	Panel Data	MCP Model	-1.93 to -0.13	
Yoo et al.	2014	Phoenix, AZ 2000-2003	Panel Data	MDP Model	-0.66 to -1.55	0.036

Existing studies also examine the effectiveness of non-price programs (Lee 1981, Lee and Warren 1981, Shaw and Maidment 1987, Moncur 1987, Shaw and Maidment 1988, Woo 1994, Renwick and Archibald 1998, Rensick and Green 2000, Howe and Goemans 2002, Kenney et al 2004, and Schuck and Profit 2004). Non-price programs are primarily examined using water demand function (see equation (1)) and dummy variables indicating the periods when a specific program was in place (e.g., Kenney et al. 2008, Garcia-Valinas 2006). Several studies examined effectiveness of non-price programs using water demand on city- or utility-wide scales, and this analysis did not allow evaluating effectiveness of the programs targeting specific audiences, or the effectiveness of specific non-price programs (Kenney et al., 2008; Syme et al., 2000). For example, Michelsen et al. (1999) found that non-price conservation programs (such as public service announcements, bill inserts, water conservation device distribution, demonstration gardens, and ordinances and regulations) reduced water use by 1.1% to 4.0% in seven southwestern U.S. cities. However, non-price programs used in different cities varied in their design and implementation, and hence, the estimates of the non-price program effectiveness cannot be generalized. Existing studies recommend collecting individual-level water use data and detailed and consistent information about non-price programs to assess the effectiveness of individual non-price programs (Borisova and Useche 2013).

A growing number of economic studies examines the effectiveness of non-price programs by explicitly modelling household utility from water use activities. For example, Brennan et al. (2007) examine welfare impact of watering restrictions implemented in Australia. The authors developed a household production model of optimal customer choice between leisure and lawn quality. In Australia, watering restrictions ban sprinkler irrigation only while irrigation through hand-held hose is allowed. Hence, households have a choice to substitute leisure time and lawn quality (with lawn quality maintained by hand-watering). The study showed that depending on the households' preferences for "greenness" of the lawn and households' time costs, 2-day per week watering restrictions can result in 0% to 36% reduction in water use (with high water use reduction predicted for households with high costs of leisure time). Such explicit modelling of household utility for water use activity provides strong theoretical background for the analysis of alternative demand management programs. However, information about household preferences is largely unavailable, and as a result, such method requires making assumptions about preferences for lawn characteristics and time allocation for a "typical" water user. To avoid making strong assumptions, in this study, we analyze effectiveness of non-price programs using monthly water, ad-hoc demand function (1), and dummy variables indicating the periods when water use restrictions (along with the inspection and enforcement components) were imposed.

Data

In this paper, we examine the effectiveness of price and non-price water demand management programs, using an example of Alachua County in the north-central Florida.

Similar to other local governments in Florida and other states in US, Alachua County relies on mandatory irrigation restrictions to encourage residential conservation. Residential landscape irrigation is prohibited between 10 am and 4 pm, and is limited to once a week during Eastern Standard Time period (winter months), and twice a week during Daylight Savings Time (summer months). In addition, irrigation time period should be limited to one hour per zone per irrigation day (or to ¾ inch). Exceptions are allowed for micro-irrigation systems, new landscapes (for 60 days after planting), hand-held watering with an automatic shut-off valve, and reclaimed water use.

Alachua County monitors compliance with irrigation restrictions by visiting high water use neighborhoods outside of the allowed irrigation time period. Households that are identified as non-complying with irrigation restrictions receive warning letters with information about potential citations and fines for non-compliance. The residential inspection program was initiated in May 2011, and in May 2011 – May 2013, roughly 800 potential violations were identified and were sent warning letters.

Gainesville Regional Utilities (GRU) is the primary water provider for Gainesville and surrounding areas in Alachua County. GRU employs three-block inclining price structure, which changes every year to account for inflation and to encourage water conservation. The water rates are effective starting from October of each year (e.g., 2012-2013 year starts in October 2012 and ends in September 2013). For example, for 2007-2008 year, GRU used customer charge of $5.35/month, and the inclining rates were $1.56 per thousand gallons for the first price block (first 9 thousand gallons), $2.82 per thousand gallons for the second price block (10 – 24 thousand gallons), and $4.93 per thousand gallons for the third block (over 25 thousand gallons). For those on separate irrigation meter, irrigation use was charged at $2.82 per thousand gallons for the first 15 thousand gallons, and $4.93 per thousand gallons for the use over 15 thousand gallons (in addition to $5.35 monthly customer charge).

Every year, water rates are indexed to account for inflation and encourage conservation. The rate increase is approximately 4 to 8 percent per year. Thus, in 2012-2013 season, the prices that customers paid for one thousand gallons were $2.20, $3.75, and $6.00 for each of the price blocks. The irrigation block rates were $3.75 and $6.00. In addition, starting in 2011 – 2012 season, GRU changed the length of the first and second price blocks to 7 and 20 thousand gallons for the combined / indoor water use (instead of 9 and 24 thousand gallons). For irrigation water use, the length of the first price block was also reduced to 13 thousand gallons (instead of 15 thousand gallons) and costumer charge raised to $8.7 per month.

The dataset used in this study consists of monthly water use records for 3592 households in Alachua County, Florida, for the period from January 2008 to May 2013. To select the sample of households, first, households within GRU's service area that received warning letters from Alachua County were identified. After removing repeated warnings and warnings sent to properties classified as non-residential, 559 households were identified. Subdivisions in which these households resided were pinpointed (using information from Alachua County property appraiser), and a sample of additional 1443 households were randomly selected. Finally, the Alachua County property appraiser database was used to randomly select additional 1590 households residing in all subdivisions in Gainesville.

For this sample of households, monthly water use records were provided by GRU. The data are disaggregated into indoor use and irrigation use for the households with separate irrigation meters (approximately 12 percent of households). In turn, for the households with combined indoor / irrigation meters, total water use is reported.

Monthly weather data are available from a local weather station. Households' property characteristics are available from the local property appraiser database.

Methodology

Following Agthe and Billing (1986) and Nieswiadomy and Molina (1989; 1991), we model residential water demand using three alternative methods: instrumental variable approach, generalized 2-stage least-squares, and 3-stage least squares. The instrumental variables are modelled following Kenney et al. (2008). The analysis is conducted in STATA.

The analysis contributes to the literature in three ways. First, we examine residential water demand given a complex pricing structure in which pricing schemes depend on the type of meter the households have (specifically, separate irrigation water use meters, or combined indoor / irrigation meters). Second, we analyze the effectiveness of the enforcement program implemented by the local government (i.e., warning letters sent to the households violating irrigation restrictions). While previous studies did examine the effectiveness of inclining block pricing and residential irrigation restrictions, no studies were found that focuses on performance of an enforcement program. Third, the data used in this study has 233,480 observations for 3592 households, which is one of the largest datasets used in these type of studies.

Following Agthe and Billing (1986) and Nieswiadomy and Molina (1989; 1991), three techniques are used to model monthly household water demand (q_{it}): 3SLS simultaneous estimation, generalized two-stages least square (G2SLS) and fixed effect instrumental variable panel estimation. In contrast to these studies, we use dynamic model, i.e., we include the previous month water use, q_{it-1}, as an independent variable (to reflect the fact that water use is a habit, and it may take a few months to change this habit in response to changing weather, price, or non-price water demand management programs). Thus the water demand model is:

$$q_{it} = \alpha_0 + \alpha_1 MP_{it-1} + \alpha_2 RP_{it-1} + \alpha_3 q_{it-1} + \alpha_4 Income_{it} + \alpha_5 Warnings_{it} + \alpha_6 Temp_t + \alpha_7 Pcip_t + \alpha_8 Irr_t + u_{it} \tag{10}$$

where q is water use for household ith in month t; *MP* is marginal price in cents; and *RP* is rate structure premium (defined as the actual water bill minus the bill that would have been paid if all water were purchased at the marginal price). In turn, *Temp* and *Prcip* are monthly temperature and precipitation; *Irr* is the dummy for the months from March to October (i.e., the period when irrigation is allowed twice a week, as opposed to once a week during the rest of the year); and *Warnings* includes two dummies to control for the water use during the three months before the warning letter, as well as four months after a household was sent a warning letter. A proxy variable is used to capture household's income. Following Nieswiadomy and Molina (1989), *Income* was constructed by using house values (as appraised in 2013) and dividing it by the monthly Housing Consumer Price Indices (with December 1999 being the baseline level of 100) (U.S. Bureau of Labor Statistics 2014). Semi-log specification for the function was used (with natural logarithm used for all the variables in the model except dummy variables).

MP and *RP* are estimated by using fixed effect instrumental variable (IV) and random effect generalized two stage least square (G2SLS) estimators. The instruments for *RP* and *MP* include the lagged values of all endogenous and exogenous variables for which the information was available. The first stage equations are

$$\begin{aligned} &MP_{it-1} = \\ &= \delta_0 + \delta_1 MP_{it-2} + \delta_2 RP_{it-2} + \delta_3 Age_{it} + \delta_4 Bed_{it} + \delta_5 D\_pool_t + \delta_6 TotalArea_t + ExVar_{it} + u_{it}^1 \end{aligned} \tag{11}$$

$$\begin{aligned} &RP_t = \\ &= \beta_0 + \beta_1 MP_{t-2} + \beta_2 RP_{t-2} + \beta_3 Age_t + \beta_4 Bed_t + \beta_5 D\_pool_t + \beta_6 TotalArea_t + ExVar_t + u_t^2 \end{aligned} \tag{12}$$

where *Age* refers to the age of the house, *Bed* refers to the number of bedrooms in the house, *D_pool* is a dummy variable indicating pools, *TotalArea* is the total property area, and *ExVar* is a vector of all the exogenous variables mentioned above (i.e., *Temp, Prcip, Irr, Warnings,* and *Income*). All price variables were adjusted by Consumer Price Indices with December 1999 equal to 100 (U.S. Bureau of Labor Statistics 2014).

For three stage least square (3SLS) method, equations (10), (11) and (12) are estimated simultaneously:

$$q_{it} = f(MP_{it-1}, RP_{it-1}, q_{it-1}, Income_{it}, Warnings_{it}, Temp_t, Pcip_t, Irr_t; \alpha)$$

$$MP_{it-1} = f(MP_{it-2}, RP_{it-2}, Age_{it}, Bed_{it}, D\_pool_t, TotalArea_t; \delta) \qquad (13)$$

$$RP_t = f(MP_{it-2}, RP_{it-2}, Age_{it}, Bed_{it}, D\_pool_t, TotalArea_t; \beta).$$

In response to the critics of previous studies, Agthe and Billings (1986) tested the hypothesis of the presence of simultaneity bias in IV methodology, and their result is in favor of utilizing 3SLS method to estimate the price elasticity of demand. Moreover, 3SLS method is relatively easy to estimate and it generally produces results consistent with previous studies. Additionally, all three methodologies used in this study (IV, 2SLS, and 3SLS) eliminate endogeneity of price measures by introducing instrumental variables, and panel data allows us to control for variables that we cannot observe or measure and that accounts for individual heterogeneity problem (Baltagi, 2008).

Results

Descriptive statistics show that customers with separate irrigation meters generally use more water than the customers with combined irrigation/indoor water meters (Table 2). Such customers generally reside in properties with higher values, and hence, they likely have higher incomes than the rest of the sample.

Table 2. Descriptive Statistics

Variables	Units	Observations	Average	Minimum	Maximum
Combined Water Use	KG/month	196,627.00	8.34	0.00	326.00
Indoor Water Use	KG/month	30,356.00	5.13	0.00	200.00
Outdoor Water Use	KG/month	30,364.00	11.72	0.00	696.00
Dummy-Warning letter		233,480.00	0.03	0.00	1.00
Average Precipitation	Inches/day	233,480.00	0.89	0.00	4.15
Average Temperature	Degrees C	233,480.00	20.50	8.80	28.90
House Age	years	233,480.00	20.81	0.00	90.00
Number of Bedrooms		233,480.00	3.38	0.00	5.00
Dummy-Pool		233,480.00	0.25	0.00	1.00
Total Area	Sq. ft	233,480.00	2,954.30	400.00	20,639.00

Households using combined water meters. Preliminary estimation results for the water use in the subsample of households with combined meters show that most of the coefficients in the models are statistically significant and have the expected signs; furthermore, the values of the coefficients are similar among IV, 2SLS, and 3SLS models. For price elasticity, the results fall into the lower range of estimates reported in literature, ranging from almost zero (not statistically significant) in IV model to -0.063 and -0.051 in 2SLS and 3SLS models. Therefore, given a 10% increase in price the total demand can be expected to decrease by 0% to 0.6%.

The preliminary results also show that irrigation restriction (i.e., a non-price program) are effective in reducing water demand. Specifically, the coefficient for dummy_irrigation is statistically significant and positive, indicating that average water use increases from 9.3 percent to 17.6 percent in the months when irrigation is allowed twice a week (as opposed to once a week). Note that although the model explicitly accounts for the weather conditions, additional steps may be required to decouple the effect of weather and irrigation restrictions on water use. Irrigation restrictions are imposed to reflect weather conditions (i.e., the restrictions are relaxed to two days per week when the weather is warmer and the precipitation is higher). Hence, the effect of the restrictions may be masked by the changes in weather. Still, based on our preliminary result, we can speculate that if irrigation is allowed seven days as opposed to two days a week, the water use can increase by up to ($\frac{7\ days}{2\ days}$) times the estimated percentage, or by 32.6% - 61.6%. This speculative analysis disregards the reduction in marginal utility from additional water use, and hence, it provides an upper bound estimate for potential increase in water use that may result in eliminating irrigation restrictions.

For the inspection component associated with the irrigation restrictions, the coefficient for one of the dummy variables shows an increase in water use for the households violating the restrictions. In three months prior to the warning letters, households are estimated to use 14.0% - 14.6% more water per month then their long-term average. Such an increase in water use shows that warning letters correctly identify and target periods of high water use on household level. Moreover, descriptive statistics (not reported here) shows that households receiving the warning letters on average use more water than the averages for their subdivisions, indicating correct targeting by the County inspection program of the high water users on subdivision levels. The second dummy variable indicates that in the period 4 months after the letter, household water use level reduces to pre-peak levels (i.e., to long-term average), showing that inspection programs are effective. In our sample of households, only 15.6 percent were identified as violating irrigation restrictions (these households were sent warning letters, 559 out of 3592 households). Hence, even though the program is effective, the reduction in the total water demand that can be attributed to the inspection program *per se* is small in comparison with the potential effect of price increase or changes in the irrigation restrictions. However, an argument can be made that the effectiveness of the irrigation restriction program would be smaller in the absence of the inspection component.

The results suggest that households on combined meters do respond to both price- and non-price water conservation programs examined: irrigation restriction, price increases, and irrigation inspections. Preliminary estimation results show that irrigation restriction can have higher impact on water use in comparison with modest price increase of 4 to 8 percent typically used by GRU.

Table 3. Preliminary Estimation Results for Households Using Combined Water Meters

	IV	**G2SLS**	**3SLS**
Intercept	-32.810***	-0.672***	-0.746***
	(1.914)	(0.011)	(0.030)
Marginal Price	0.021	-0.063***	-0.051***
	(0.017)	(0.011)	(0.011)
Rate Premium	0.001	-0.042***	-0.009***
	(0.002)	(0.001)	(0.001)
Lag_Usage	0.466***	0.459***	0.762***
	(0.010)	(0.007)	(0.007)
Dummy_warning letter	0.140***	0.140***	0.146***
(3 months before letter)	(0.014)	(0.016)	(0.016)
Dummy_warning letter	0.005	-0.010	-0.020
(4 months after letter)	(0.013)	(0.014)	(0.014)
Property Value	2.801***	0.125***	0.094***
	(0.159)	(0.002)	(0.002)
Precipitation	-0.041***	-0.053***	-0.054***
	(0.002)	(0.002)	(0.002)
Temperature	0.008***	-0.004***	-0.001**
	(0.000)	(0.000)	(0.000)
Dummy_irrigation	0.093***	0.192***	0.176***
	(0.004)	(0.005)	(0.005)
R^2	0.24	0.95	0.58

Notes: Asterisks (*, **, ***) represent significant at the 10%, 5% and 1% level, respectively.

Households using separated water meters: indoor water use. Preliminary estimation results for the households on separate indoor meters show reasonable water demand model fit, with statistically significant coefficients generally having expected signs. The price elasticity of demand varies from -0.061 to -0.127 (with 10% significance level). As expected, these elasticities smaller in absolute value than the elasticities for combined water use discussed above. Indoor water use primarily includes non-discretionary activities that cannot be adjusted in response to price change. Dummy variables for warning letters and irrigation restrictions are mostly not statistically significant. This result is also expected, since the warning letters and restrictions target outdoor water use. Surprisingly, IV model shows a negative and statistically significant coefficient (-0.05) of the dummy indicating the period of four months after the warning letters. One can argue that such a letter can remind households about the need to conserve water, resulting in changes in both indoor and outdoor water use. In addition, for irrigation restrictions (dummy_irrigation), the coefficient is statistically significant in G2SLS model (0.020 at the 5% significance level). Similar argument can be made that changes in irrigation restrictions from one to two days per week may imply that water conservation is no longer important, influencing household choices both indoor and outdoor. It is important to note that the coefficients for the variables describing both warning letters and irrigation restrictions are small, implying marginal changes in indoor water use.

Table 4. Preliminary Estimation Results for Households Using Separate Indoor Water Meters

	IV	**G2SLS**	**3SLS**
Intercept	-21.915*** (3.755)	-0.530*** (0.093)	-0.369*** (0.092)
Marginal Price	-0.061* (0.034)	-0.127*** (0.024)	-0.079*** (0.024)
Rate Premium	-0.053*** (0.004)	-0.047*** (0.003)	-0.028*** (0.002)
Lag_Usage	0.137*** (0.017)	0.497*** (0.010)	0.659*** (0.009)
Dummy_warning letter (3 months earlier)	-0.022 (0.024)	0.009 (0.026)	0.001 (0.025)
Dummy_warning letter (4 months later)	-0.050** (0.021)	-0.006 (0.023)	-0.016 (0.022)
Property Value	1.838*** (0.296)	0.106*** (0.007)	0.073*** (0.007)
Precipitation	-0.010** (0.004)	-0.017*** (0.004)	-0.016*** (0.004)
Temperature	-0.001 (0.001)	-0.002** (0.001)	-0.001 (0.001)
Dummy_irrigation	0.010 (0.009)	0.020** (0.009)	0.008 (0.009)
R^2	0.06	0.90	0.45

Notes: Asterisks (*, **, ***) represent significant at the 10%, 5% and 1% level, respectively.

Households using separated water meters: outdoor water use. Table 5 presents preliminary results for the model of outdoor water demand for the households with separate outdoor water-meter. Similar to the results described above, the models perform reasonably well, with most of the coefficients being statistically significant with the expected signs. The estimates of price elasticity (ranging from -0.24 to -0.31) fall within the range reported in other studies, and the results are statistically significant at 1% level. The demand is inelastic, and it is expected to decrease by 2.4% to 3.1% given a 10% increase in price.

For the non-price program, dummy_irrigation coefficients are statistically significant and positive as predicted. The results suggest that the demand is 22 - 39 percent higher in irrigation season when the allowed irrigation frequency is twice a week (vs once a week).

Moreover, dummy variables for warning letter show that the water use peaks three months prior to warning letter (with the increase in water use of 16% - 20% per month in comparison with the long-run average). In the four months following the warning letter, the demand drops to the long-run average or decreases even further (by up to 7% below the long-term average). Again only 15.6% of the households in the sample received warning letter, and hence their effect on aggregate water use of all customers is relatively small. Having said that, the inspections and warning letters likely contribute to the effectiveness of irrigation restrictions described above.

Table 5. Preliminary Estimation Results for Households Using Separate Outdoor Water Meters

	IV	**G2SLS**	**3SLS**
Intercept	-33.031*** (7.281)	0.082 (0.245)	-0.861*** (0.243)
Marginal Price	-0.242*** (0.084)	-0.306*** (0.069)	-0.239*** (0.068)
Rate Premium	-0.012*** (0.004)	-0.031*** (0.002)	-0.006** (0.002)
Lag_Usage	0.292*** (0.046)	0.223*** (0.035)	0.715*** (0.034)
Dummy_warning letter (3 months earlier)	0.188*** (0.042)	0.198*** (0.046)	0.162*** (0.044)
Dummy_warning letter (4 months later)	-0.016 (0.038)	-0.010 (0.041)	-0.069* (0.039)
Property Value	2.747*** (0.569)	0.137*** (0.016)	0.133*** (0.016)
Precipitation	-0.069*** (0.007)	-0.083*** (0.008)	-0.076*** (0.008)
Temperature	0.008*** (0.002)	-0.006*** (0.002)	-0.005*** (0.002)
Dummy_irrigation	0.216*** (0.019)	0.344*** (0.022)	0.389*** (0.021)
R^2	0.19	0.84	0.39

Notes: Asterisks (*, **, ***) represent significant at the 10%, 5% and 1% level, respectively.

Finally, tables 6 – 8 summarize preliminary estimation results for the endogenous price variables for the three categories of water use: combined, indoor, and outdoor. The results show that the variables used to model the endogenous variables are selected well, and most of them are statistically significant.

Table 6. Endogenous Variables, Households Using Combined Water Meters

(<u>Preliminary results</u>)

	IV		G2SLS		3SLS	
	MP	**RP**	**MP**	**RP**	**MP**	**RP**
Intercept	-10.413‡ (0.691)	308.229‡ (14.311)	-0.193‡ (0.020)	5.454‡ (0.412)	0.093‡ (0.005)	-0.717‡ (0.093)
Lag_Usage	0.319‡ (0.001)	-6.385‡ (0.017)	0.272‡ (0.001)	-5.563‡ (0.015)		
Dummy_warning letter (3 months earlier)	0.016‡ (0.005)	0.004 (0.111)	0.025‡ (0.006)	-0.203* (0.118)		
Dummy_warning letter (4 months later)	0.009* (0.004)	0.173* (0.097)	0.015‡ (0.005)	0.071 (0.102)		
Property Value	0.759‡ (0.057)	-24.115‡ (1.181)	-0.004† (0.002)	0.095‡ (0.037)		
Precipitation	-0.002‡ (0.001)	-0.022* (0.014)	-0.007‡ (0.001)	0.044‡ (0.015)		
Temperature	0.002‡ (0.000)	-0.056‡ (0.003)	0.003‡ (0.000)	-0.053‡ (0.003)		
Dummy_irrigation	-0.053‡ (0.002)	0.499‡ (0.031)	-0.054‡ (0.002)	0.449‡ (0.034)		
Lag_Marginal Price	0.337‡ (0.007)	4.553‡ (0.136)	0.889‡ (0.004)	-0.039 (0.074)	0.894‡ (0.005)	0.195† (0.095)
Lag_Rate Premium	0.010‡ (0.000)	0.361‡ (0.007)	0.031‡ (0.000)	0.246‡ (0.004)	0.013‡ (0.000)	0.623‡ (0.005)
House Age	0.062‡ (0.001)	-0.646‡ (0.013)	0.000 (0.000)	0.004‡ (0.001)	-0.001‡ (0.000)	0.031‡ (0.001)
Number of Bedrooms			-0.010‡ (0.001)	0.199‡ (0.019)	0.016‡ (0.001)	-0.331‡ (0.024)
Dummy_pool			0.009‡ (0.001)	-0.199‡ (0.028)	0.035‡ (0.002)	-0.732‡ (0.036)
Total Area			0.000 (0.000)	0.000 (0.000)	0.000‡ (0.000)	0.000‡ (0.000)
R^2	0.62	0.54			0.48	0.43

Notes: The signs (*,†, ‡) represent significant at the 10%, 5% and 1% level, respectively.

Table 7. Endogenous Variables, Households Using Separate Indoor Water Meters

(Preliminary results)

	IV		G2SLS		3SLS	
	MP	**RP**	**MP**	**RP**	**MP**	**RP**
Intercept	-4.437‡ (1.396)	1.551 (29.325)	0.414‡ (0.063)	-8.106‡ (1.321)	-0.029‡ (0.008)	1.239‡ (0.173)
Lag_Usage	0.195‡ (0.002)	-4.164‡ (0.044)	0.149‡ (0.002)	-3.228‡ (0.036)		
Dummy_warning letter (3 months earlier)	0.009 (0.008)	-0.168 (0.172)	-0.006 (0.009)	0.165 (0.181)		
Dummy_warning letter (4 months later)	0.012* (0.007)	-0.109 (0.152)	-0.001 (0.008)	0.193 (0.158)		
Property Value	0.308‡ (0.110)	0.518 (2.303)	-0.053‡ (0.005)	1.166‡ (0.114)		
Precipitation	-0.006‡ (0.001)	-0.015 (0.027)	-0.008‡ (0.001)	0.001 (0.029)		
Temperature	0.001‡ (0.000)	-0.018‡ (0.005)	0.002‡ (0.000)	-0.025‡ (0.006)		
Dummy_irrigation	-0.045‡ (0.003)	0.310‡ (0.061)	-0.048‡ (0.003)	0.363‡ (0.066)		
Lag_Marginal Price	0.636‡ (0.018)	0.658* (0.381)	1.016‡ (0.008)	-1.539‡ (0.158)	1.009‡ (0.008)	-1.090‡ (0.175)
Lag_Rate Premium	0.020‡ (0.001)	0.241‡ (0.018)	0.031‡ (0.000)	0.270‡ (0.009)	0.023‡ (0.000)	0.472‡ (0.010)
House Age	0.037‡ (0.002)	-0.214‡ (0.035)	0.000† (0.000)	-0.003 (0.003)	0.000 (0.000)	0.002 (0.003)
Number of Bedrooms			0.000 (0.002)	0.008 (0.036)	0.006‡ (0.002)	-0.126‡ (0.039)
Dummy_pool			-0.001 (0.002)	0.006 (0.045)	0.001 (0.002)	-0.026 (0.047)
Total Area			0.000‡ (0.000)	0.000‡ (0.000)	0.000‡ (0.000)	0.000‡ (0.000)
R^2	0.58	0.34			0.50	0.29

Notes: The signs (*,†, ‡) represent significant at the 10%, 5% and 1% level, respectively.

Table 8. Endogenous Variables, Households Using Separate Outdoor Water Meters (Preliminary results)

	IV		G2SLS		3SLS	
	MP	**RP**	**MP**	**RP**	**MP**	**RP**
Intercept	-43.537‡	1786.298‡	-0.529‡	43.581‡	0.230‡	-7.406‡
	(2.317)	(154.625)	(0.095)	(6.288)	(0.025)	(1.648)
Lag_Usage	0.209‡	-13.574‡	0.202‡	-13.323‡		
	(0.002)	(0.125)	(0.002)	(0.112)		
Dummy_warning letter (3 months earlier)	-0.012	0.831	-0.006	0.679		
	(0.010)	(0.695)	(0.010)	(0.694)		
Dummy_warning letter (4 months later)	-0.008	1.028*	-0.007	1.042*		
	(0.009)	(0.621)	(0.009)	(0.614)		
Property Value	3.424‡	-139.102‡	0.029‡	-1.751‡		
	(0.183)	(12.190)	(0.008)	(0.535)		
Precipitation	0.005†	-0.282†	-0.003*	-0.015		
	(0.002)	(0.122)	(0.002)	(0.123)		
Temperature	0.001‡	-0.090‡	0.001*	-0.037		
	(0.000)	(0.026)	(0.000)	(0.026)		
Dummy_irrigation	-0.040‡	0.556*	-0.034‡	0.237		
	(0.005)	(0.315)	(0.005)	(0.320)		
Lag_Marginal Price	0.377‡	9.263‡	0.861‡	1.612*	0.853‡	3.478‡
	(0.032)	(2.109)	(0.014)	(0.926)	(0.018)	(1.214)
Lag_Rate Premium	0.004‡	0.235‡	0.011‡	0.179‡	0.006‡	0.515‡
	(0.000)	(0.032)	(0.000)	(0.015)	(0.000)	(0.019)
House Age	0.056‡	-1.531‡	0.001‡	-0.046‡	-0.001‡	0.106‡
	(0.003)	(0.177)	(0.000)	(0.012)	(0.000)	(0.014)
Number of Bedrooms			0.012‡	-0.757‡	0.002	-0.110
			(0.002)	(0.159)	(0.003)	(0.204)
Dummy_pool			-0.011‡	0.611‡	0.016‡	-1.116‡
			(0.003)	(0.203)	(0.004)	(0.250)
Total Area			0.000	0.000	0.000‡	-0.001‡
			(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.52	0.47			0.30	0.25

Notes: The signs (*,†, ‡) represent significant at the 10%, 5% and 1% level, respectively.

Summary of the preliminary estimates for price and income elasticities are reported in Table 9. Price elasticity results are discussed above. For income elasticity (modeled using a proxy variable based on indexed property values), the results show that income elasticities ranged from 0.07 to 0.14 at the 1% significance level when G2SLS and 3SLS models are taken into account. That is, given 10% increase in income, the demand is expected to increase by 0.7% to 1.4%. The income elasticities are also within the range reported in the previous studies (except the elasticity estimates from IV model that exceed our expectations).

Table 9. Price and Income Elasticities* for Households with Various Water-Meters

	Combined Water-Meter		**Indoor Water-Meter**		**Outdoor Water-Meter**	
	Price Elasticity	**Income Elasticity**	**Price Elasticity**	**Income Elasticity**	**Price Elasticity**	**Income Elasticity**
IV	0.021 (0.017)	2.801*** (0.159)	-0.061* (0.034)	1.838*** (0.296)	-0.242*** (0.084)	2.747*** (0.569)
G2SLS	-0.063*** (0.011)	0.125*** (0.002)	-0.127*** (0.024)	0.106*** (0.007)	-0.306*** (0.069)	0.137*** (0.016)
3SLS	-0.051*** (0.011)	0.094*** (0.002)	-0.079*** (0.024)	0.073*** (0.007)	-0.239*** (0.068)	0.133*** (0.016)

***** modeled using proxy variables for household income

Note that this study has a set of limitations. We do not account for the interaction of price- and non-price programs. For example, Kenney et al. (2008) examined water use in Aurora, CO, in 1997-2005, and found that the demand management programs influence each other. For example, the effect of water use restrictions on water use given zero water prices is estimated to be 31%. The estimated effect reduces to 12% when the average exiting water prices are considered. Similarly, when the restrictions are in place, customers are less responsive to price changes: price elasticity without restrictions is -0.60 on average, and the elasticity during the restriction period is -0.37.

In this study, we also did not consider the effect of wastewater fees on water use, as well as seasonal changes in price elasticity for the combined indoor&outdoor water use. The study focuses on short-run elasticity, and no attempt was made to estimate long-run elasticities.

Conclusion

Preliminary results show that the panel data regression models used to examine water demand have good fit, and most of the variables have expected and statistically significant effects on water use. Implementing residential irrigation restrictions, irrigation inspection program, and price increases have a significant negative effect on monthly water use.

When price elasticity results are examined across the three models and for different water use categories (combined, indoor, and outdoor), it can be seen that outdoor use is most responsive to price changes. However, even for this category of water use, 10 percent increase in price is estimated to induce only 3 percent reduction in water use. In other words, to achieve 10 percent reduction in use, prices should be increased by 30 percent or more. Given that currently the maximum GRU water rate is $6 for a thousand gallon, such an increase would results in rates above $10 per thousand gallons. While this increase may not be politically feasible in Florida, it is not unrealistic. For example, in Austin, TX, the maximum price charged for water use about 20 thousand gallons is $12.55 per thousand gallons (Austin Water Utility 2013). Political feasibility of price increase can be improved by focusing on high price blocks only.

Irrigation restrictions are also effective in curbing water use (even though the effects of weather and irrigation restrictions can be difficult to decouple). Changing allowed irrigation frequency from once a week to twice a week results in up to 40 percent increase in water use. Irrigation inspections likely contribute to effectiveness of the irrigation restrictions in Alachua County.

Comprehensive economic analyses of residential water demand is of great need for water utility companies and local and state agencies implementing a variety of residential water conservation programs. These study results can help increase effectiveness of such programs, and select price and non-price programs that lead to the expected water use change for the residential customers.

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