Price elasticity of residential water demand in California

Juneseok Lee and Stephanie A. Tanverakul

ABSTRACT

This study used meta-analysis to assess the influence of price/price structures on residential water demand in two selected urban areas in California: East Los Angeles and South San Francisco. Monthly usage data for the years 2002–2011 were utilized to determine and compare price elasticities for periods when uniform and tiered rates were charged using fixed effects panel regression and Instrumental Variable methods. Price elasticities in East Los Angeles and South San Francisco were −0.39 and −0.22 under uniform rates and −0.44 and 0.43 under tiered rates, respectively. When customers in each city were divided into three groups based upon their lot sizes, those with larger lot sizes tended to react to pricing systems more strongly than those living on smaller lots. These findings will be helpful for water demand stakeholders and policymakers seeking to design and implement more effective water pricing policies to support sustainable water conservation efforts.

Key words | price elasticity, residential water demand and water conservation

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INTRODUCTION

In California, water conservation has become a major priority as state agencies are faced with the challenge of meeting exacting new water conservation goals such as the recent 20 by 2020 bill, which requires a 20% reduction in per capita urban water use by the year 2020 (California Senate Bill X7-7). Water prices are known to be an effective way of managing residential water consumption, but the degree of reduction achieved can vary considerably based upon local factors including, but not limited to, current levels of water use, climate, the price policy itself, the estimation method and interpretation to evaluate policy effectiveness (Arbués *et al*. 2003; Dalhuisen *et al*. 2003; Olmstead & Stavins 2007). Since the majority of residential water utility costs are recovered through user rates and specific charges, when designing rate structures planners must consider aspects such as the need to maintain financial stability under state laws and regulations, different political agendas, environmental externalities, customer affordability and equity issues (Hildebrand *et al*. 2009; Ash 2012; Beecher 2012).

The main objective of conservation-oriented pricing is to create an appropriate price that sends a clear signal to high water users to encourage them to reduce their water use by making them aware of the amount of water they actually consume (Teodoro 2002). Increasing block rate structures have thus become popular with utilities seeking to balance their finances and decrease customer consumption, enabling them to achieve equity without negating cost efficiency, as well as ensuring full cost recovery (Arbués *et al.* 2003; Ash 2012; Beecher 2012).

In this paper, the authors address two major issues using the case studies of East Los Angeles and South San Francisco in California: (i) how price influences water demand under both uniform and tiered rate structures and (ii) how price impacts different household characteristics. The analysis is based on 10 years of monthly household level water use data (2002–2011) collected by the California Water Service Company (Cal Water), an investor owned water utility in California. Crucial factors for designing pricing policies for residential water demand management, including price elasticity estimation and water rate structures, are discussed in detail. The price elasticity of residential water demand is estimated for customers under a uniform rate structure as well as those who have been switched to an increasing tiered rate structure. To further

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investigate the impact of different household characteristics, customers are divided into three classes based on the size of their lot (high, medium and small) and the price elasticity is estimated to compare the responsiveness of each class.

LITERATURE REVIEW

According to the law of demand in economics, all other things being equal, increasing the price of a commodity should result in a decrease in quantity demanded. The demand reduction associated with an increase in price is termed the *price elasticity* of demand (Mays 2010). However, residential water use is a unique product since it has no replacement for basic needs such as bathing, drinking, and washing. So, the marginal utility tends to be high at the start when fulfilling essential needs, but decreases once those needs are met. It is consequently the high discretionary uses of residential water that has been the major target for pricing strategies where higher prices are set for greater water use (Martinez-Espineira & Nauges 2004). The wide range identified by previous price elasticity studies demonstrates the critical need to model the detailed characteristics of customers in order to design effective demand management programs (Arbués *et al.* 2003).

In a meta-analysis contrasting and combining the results from a number of different studies of the price elasticity of residential water demand for the period from 1967 to 1993, Espey *et al.* (1997) found an average price elasticity of −0.51 and noted that 90% of the 124 estimates of the price elasticity of demand were between 0 and −0.75. On average, this translates to a 5.1% decrease in water demand for every 10% increase in price. Similarly, Dalhuisen *et al.* (2003) determined a mean price elasticity of −0.41 in their meta-analysis of 300 price elasticity studies conducted between 1963 and 1998. Specifically in California, Renwick & Archibald (1998) estimated the residential water price elasticity of demand to be −0.33.

The studies of residential water price elasticity of demand reported in the published literature in the field vary considerably with regard to their methodologies, context of measurements, season, region, and customer characteristics. Michelsen (1997) demonstrated significant differences in the price elasticities of seven southwestern cities, with values ranging between −0.37 and −0.12. Household characteristics also affect how a particular household will respond to price. For example, Renwick & Green (2000) found that lower income households show greater responsiveness than wealthier households. Likewise, Renwick & Archibald (1998) found price responsiveness was five times greater in low-income households than in relatively wealthy households. Kenney *et al.* (2008) calculated the price elasticity of demand for three levels of water use and discovered that high users are more responsive than smaller users, with price elasticities of −0.75 and −0.34, respectively.

The specific end use within a household also influences price elasticity values. When household water consumption is separated into indoor and outdoor use they respond differently to price (Rawls *et al.* 2010). Water allocated to outdoor use tends to be of a discretionary nature and is first to be cut if prices increase; Howe (1982) reported the price elasticity for demand indoor during winter to be −0.06, while in the summer it was −0.57 and −0.43 for the east and semi-arid west, respectively. However, Cavanagh *et al.* (2002) suggested that consumer responsiveness to changes in price is likely to be influenced by the type of rate structure used. In their study, households facing a two-tiered increasing block rate were five times more sensitive to changes in price than households with a uniform rate structure. The choice of price elasticity estimation model, the level of detail in the data and the selected explanatory variables all have a significant impact on price elasticity (Espey *et al.* 1997; Arbués *et al.* 2003).

DATA

Cal Water provided 10 years of monthly water consumption data (January 2002–December 2011) for approximately 1,000 households in East Los Angeles and South San Francisco in California. Household ID numbers were used to protect customer privacy. For each household, the lot size, age of the house, and total number of bathrooms was specified. According to the US Department of Commerce, the median household income and median housing values are $63,038 and $313,300 for East Los Angeles and $108,004 and $648,300 respectively (2010 estimate). Yearly precipitation in East Los Angeles is 417, and 511 mm in South San Francisco.

Water use

Residential water consumption for both cities follows seasonal weather patterns, with peaks during the summer months. Figure 1 presents the average monthly household consumption from 2002 to 2011 for both cities, highlighting the seasonal variation. East Los Angeles and South San Francisco both have relatively smaller summer peaks than other typical urban cities in California, however, and the average yearly consumptions for each city are shown in Figure 2. As the graph shows, East Los Angeles' average water consumption is higher than that of South San Francisco. Also, it is noted that yearly water consumption for both cities has decreased.

Price and rate structures

From 2002 to 2011, Cal Water implemented several rate changes, with the major change being the transition from uniform to tiered rates in July 2008. However, under both rate structures, unit price increases were implemented (Figures 3 and 4). Under uniform rate structures, residents in both cities were charged a uniform unit price in addition to a fixed price based on their meter connection size (Figures 5 and 6). Under tiered rates, both East Los Angeles and South San Francisco had two tiers (Figures 3 and 4) but the tiers implemented were different: East Los Angeles lower tier was up to 8 ccf and the upper tier anything above that, whereas South San Francisco's transition point was 5 ccf.

METHODS

Uniform rates – fixed effects panel regression

The fixed effects panel regression model attempts to control for unobservable factors among each residence by assigning unique time invariant identifiers. A simplified form of a fixed effect model is as follows (Hsiao 2003):

$$y_{it} = \alpha_i + \beta \mathbf{x}_{it} + \mu_{it} \quad (1)$$

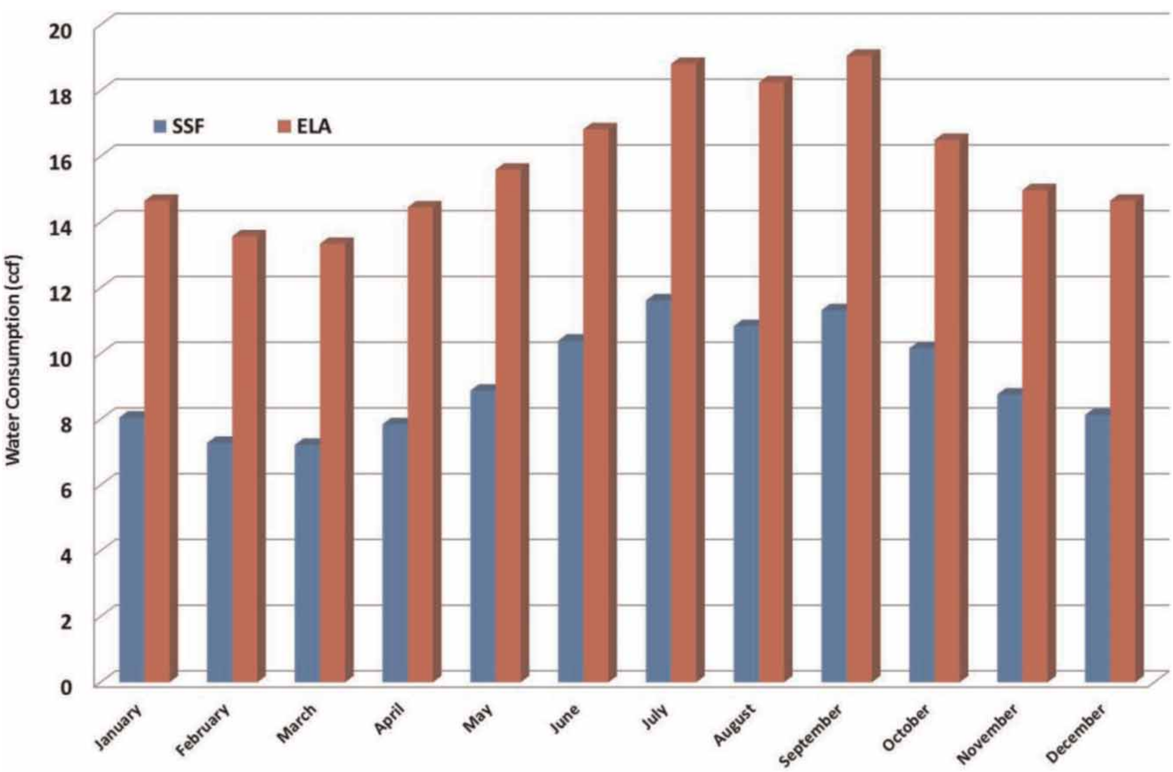

Figure 1 | Monthly average household water consumption from 2002 to 2011 (1 ccf = 3400.48 L).

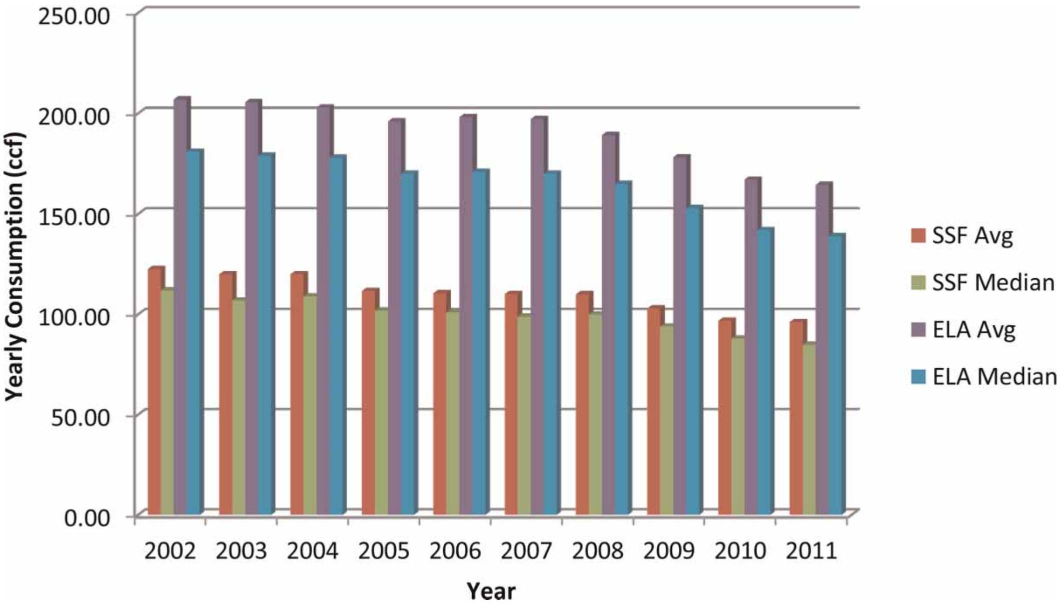

Figure 2 | Average yearly household water consumption from 2002 to 2011 (1 ccf = 3400.48 L).

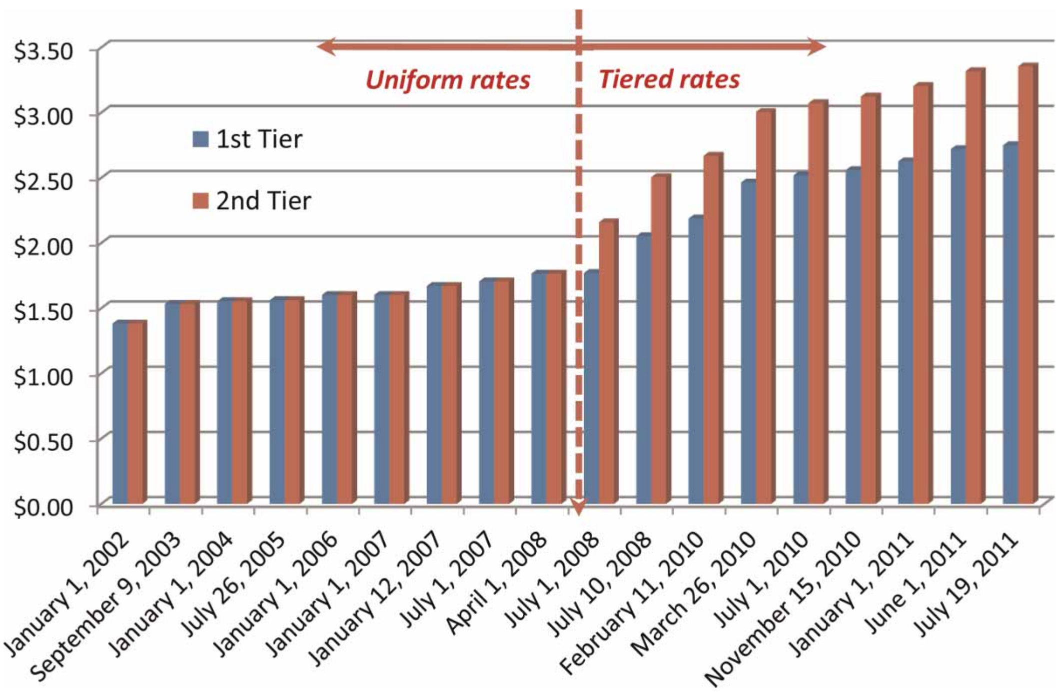

Figure 3 | East Los Angeles rate structure changes (monthly unit prices).

where $i = 1 \ldots, N$, over a time period $t = 1 \ldots T$. In this case, the intercept value, α_i, is dependent on omitted factors specific to each household i that are possibly correlated with the chosen regressors, $\boldsymbol{x}_{it}$. Any time invariant variables that may have an effect on consumption are absorbed into the intercept term, α_i. The error term, μ_{it}, represents effects from unique household factors that were both not accounted for and uncorrelated with identified regressors ($\boldsymbol{x}_{it}$).

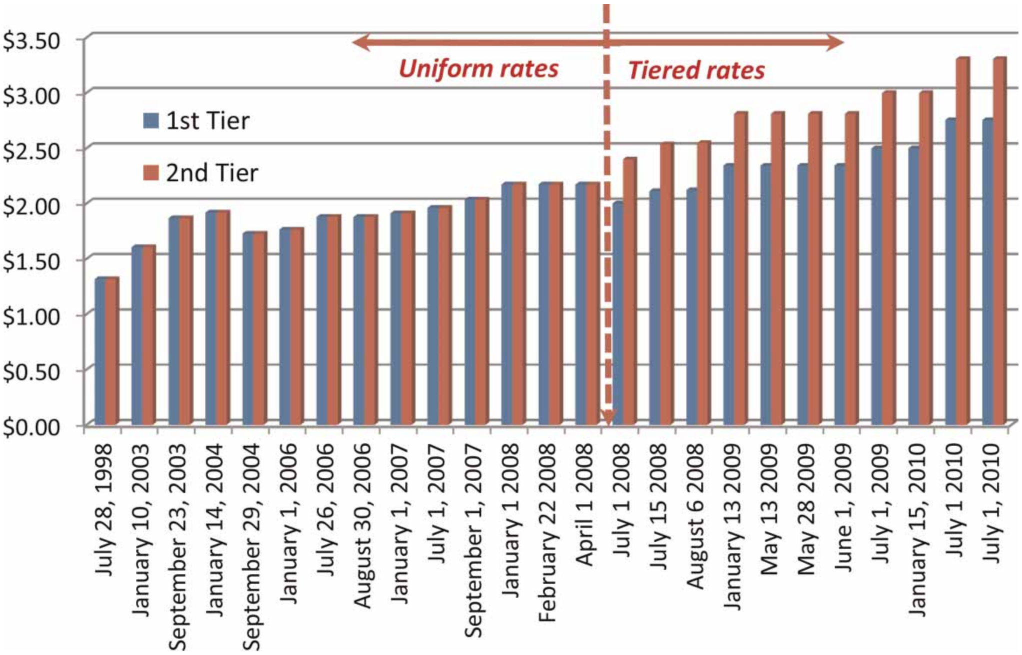

Figure 4 | South San Francisco rate structure changes (monthly unit prices).

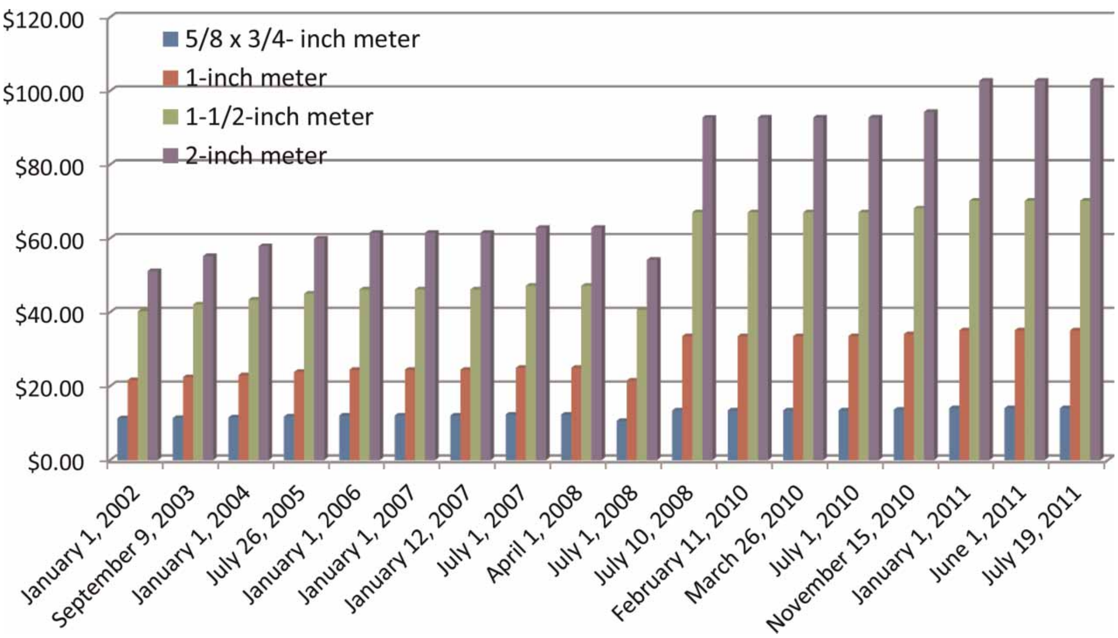

Figure 5 | East Los Angeles fixed price (monthly).

In this study, household heterogeneity was assumed to influence water use and the fixed effects model was therefore adopted for the price elasticity estimation. Chosen independent variables were regressed on the dependent variable, defined as the monthly consumption per household. The variable representing the customer response to price was modeled with marginal price. Perfectly informed customers should be expected to react to

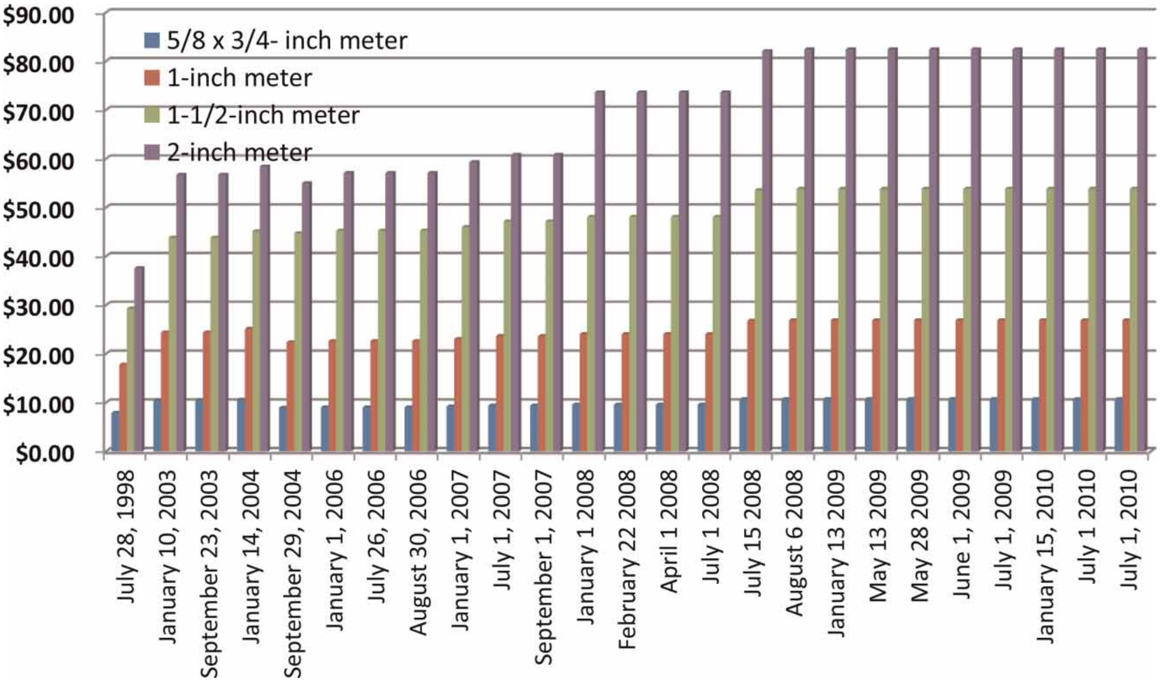

Figure 6 | South San Francisco rate structures (monthly).

marginal prices, whereas customers who do not look at their bills in detail or spend much time reviewing their bills may respond more to an average price (Nieswiadomy 1992). Marginal price was chosen to estimate the affects that volumetric pricing has on customers, and whether the price of consuming the next unit of water has a bearing on customers' choice on water use. At the time of rate change, CalWater directly informed customers of the rate structure changes. Due to this being within the period of analysis, authors assumed that customers were very aware of the unit costs they would be paying.

Other explanatory variables included the lot size, total monthly adjusted evapotranspiration (ET), number of bathrooms, the age of the house, and dummy variables for each month. Variables representing household characteristics were included in an auxiliary regression since these are time invariant and would be removed from a fixed effects model. In the log-log format, the price regression coefficient, β_1 represents the elasticity. The statistical program R was used to perform the analysis.

Tiered rates – instrumental variable

As water rate structures switched from uniform to volumetric tiered rates, the major problem in estimating water demand under tiered rates is the violation of its necessary condition that no correlation exists between the error term and any of the explanatory variables. This condition is not fulfilled under tiered rates since the price customers pay is determined by the quantity demanded (endogeneity problem), which can lead to biased results (Croissant & Millo 2008). To account for the volumetric dependency of water on price, the concept of 'instrumental variables' (IV) is adopted as a water demand estimation method (Renwick & Archibald 1998). The IV method involves a two-step estimation technique. The first step creates a price variable that aims to eliminate the endogeneity problem. This is achieved by regressing household water use onto the actual marginal price the household must pay. The predicted consumption values can then be used to estimate a price variable. The next step uses the instrumental price variable in a panel regression equation to estimate water consumption

(Barkatullah 2002). The statistical program R was again used to perform the analysis.

RESULTS AND DISCUSSION

Price elasticity under uniform and tiered rates

The analysis revealed that East Los Angeles and South San Francisco had price elasticities of −0.39 and −0.218, respectively, under uniform rates from January 2002 to July 2008 (Table 1). East Los Angeles' water demand was higher than that of South San Francisco (Figures 1 and 2), which may have influenced the resulting elasticity values. The price elasticity estimates for tiered rates from July 2008 to December 2011 had the expected negative sign for both cities (Table 1), and both were higher for tiered rates than for uniform rates.

Price elasticity for household characteristics

As Kenney *et al.* (2008) demonstrated that price elasticities differ depending upon their usage, it can be inferred that price increases may influence water use differently depending on customer characteristics. To verify Kenney *et al.*'s results, customers were divided into categories by lot sizes (small 25%, medium 50% and large 25%). The lot size was chosen as a proxy to capture specific household characteristics such as income and outdoor use since larger lot sizes are likely to be associated with higher incomes and larger landscaped areas. For both cities, a price elasticity coefficient with a negative sign was found for all three lot size categories under uniform pricing (Table 2). Price elasticity was the greatest (−0.423) in the largest lot sizes of East Los Angeles, while medium lot sizes in South San Francisco had the largest values (−0.249). These findings support the contention that response to price is dependent on both regional and household characteristics.

Table 1 | Price elasticity for ~1,000 households facing uniform and tiered rates

City	Price elasticity (uniform)	Price elasticity (tiered)
East Los Angeles[a]	−0.390	−0.437
South San Francisco[a]	−0.218	−0.425

[a]All coefficients are statistically significant ($p = 0.05$).

Table 2 | Price elasticity by lot size (small, medium, large)

	East Los Angeles	South San Francisco
Small[a]	−0.239 ($n = 273$)	−0.185 ($n = 209$)
Medium[a]	−0.385 ($n = 545$)	−0.249 ($n = 499$)
Large[a]	−0.423 ($n = 273$)	−0.157 ($n = 315$)

*All coefficients are statistically significant ($p = 0.05$).

CONCLUSIONS

Water demand price elasticity research has clearly demonstrated that pricing, together with education and plumbing code is a relevant tool for policymakers to manage water consumption. In this case study comparing East Los Angeles and South San Francisco, the authors' findings demonstrate that (i) price influences water demand under both uniform and tiered rate structure and (ii) price elasticity is affected by household characteristics.

Price elasticities of water demand differed across regions and household characteristics and when customers were charged under uniform rates and then under an increasing tiered rate structure. Under uniform rates, the price elasticity of residential water demand was −0.39 in East Los Angeles and −0.219 in South San Francisco, while for tiered rates it was −0.437 in East Los Angeles and −0.425 in South San Francisco. The difference in price elasticity between the two cities demonstrates the importance of understanding the unique population response. Household characteristics (here, the lot size) also play an important role in determining the price elasticity. The greatest price elasticity in East Los Angeles was for the large lot size group, whereas in San Francisco it was for the medium lot size group under uniform pricing.

Demand management strategies focused on water conservation are shifting towards implementing new pricing strategies (Arbués *et al.* 2003; Dalhuisen *et al.* 2003; Olmstead & Stavins 2007). For these to be effective however, the customer response to price must be clearly understood. By looking at the price elasticity across lot sizes, the price response can be explored for different user types. Policymakers should also consider the appropriate number of tiers and the percentage increase of prices in each tier for efficient water resource management. Stakeholders and policymakers can usefully implement these research outcomes when designing/implementing water price policy to support sustainable water conservation efforts.

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