The Welfare Consequences of the 2015 California Drought Mandate: Evidence from New Results on Monthly Water Demand

Steven Buck
University of Kentucky
Department of Agricultural Economics
stevenbuck@uky.edu

Mehdi Nemati
University of Kentucky
Department of Agricultural Economics
Mehdi.nemati@uky.edu

David L. Sunding
University of California, Berkeley
Department of Agriculture and Resource Economics
sunding@berkeley.edu

Selected Paper prepared for presentation at the 2016 Agricultural & Applied Economics Association and Western Agricultural Economics Association Annual Meeting, Boston, Massachusetts, July 31-August 2

Abstract

In response to the severe California drought, in April 2015, Governor Jerry Brown issued an executive order mandating statewide reductions in water use. The mandate aimed to reduce the amount of water consumed statewide in urban areas by 25% from 2013 levels. The State Water Resources Control Board (SWRCB) proposed regulatory instructions that grouped urban water utilities into nine tiers, with conservation standards ranging from 8% to 36%. In this paper we evaluate welfare losses caused by this mandate. Understanding the proposed regulation's welfare losses requires estimating water demand. Using fixed effect models and data from 2004 to 2009 on 111 urban water utilities, an annual demand curve is estimated. The estimated demand elasticity is between -0.61 and -0.1 which is heterogeneous across the regions and seasons. In the second step, we use the estimated annual demand function to recover price elasticities for a sample of 53 urban water utilities in California, which provide water for more than 20 million customers. We considered two scenarios to calculate welfare losses in Northern and Southern California: the governor's mandate, and a hypothetical 25% uniform cut back. The results for Northern California indicate an average welfare loss of $6,132 per acre-foot of shortage for a governor's mandate and $4,424 for a 25% uniform shortage. In Southern California, the average estimated welfare loss is $2,113 per acre-foot of shortage for a governor's mandate and $2,171 for a 25% uniform shortage. Results indicate the monthly household-level willingness-to-pay to avoid the governor's mandate is $36 in Northern California and $25 in Southern California. Our results suggest inefficiencies in the distribution of the percentage cutbacks between Northern California utilities from SWRCB.

Key words: California, demand, government policy, urban water utilities, water supply shortage

JEL classification: *D61, L95, Q25, Q28, Q58*

1. Introduction

The 2012-2015 California drought has been one of the most extreme on record, characterized by low precipitation and high temperatures (Shukla et al., 2015). In response to drought conditions, California governor, Jerry Brown, issued an Executive Order to reduce urban water use in 2015. The California State Water Resources Control Board (SWRCB) is responsible for the implementation of such orders. The SWRCB On May 2015, adopted an emergency regulation which required a 25 percent statewide reduction in potable urban water use between June 2015 and January 2016.

Restrictions on urban water use such as that imposed by Governor Brown is a common drought management strategy in many parts of the United States (for example, Texas, Nevada, Colorado, Arizona, and New Mexico). Most urban water restrictions focus on the residential sector (Mansur and Olmstead, 2012), because it is considered to have lower value use than multifamily residential, commercial, and industrial sectors. In California, the residential sector accounts for one-half to two-thirds of urban water use. Mandatory restrictions can be costly to enforce, time-consuming, and may require a significant investment in education and marketing. Despite these costs, politicians favoring water restrictions commonly try to gain the support of the public. Also, supporters of restrictions often claim that the public generally supports water restrictions. However, volumetric water rates are not based on variable costs alone; they are also determined by high fixed costs associated with expensive infrastructures. Therefore, the consumer surplus triangle, which is often used to determine welfare losses due to a supply disruption, is incorrect. As determined by Buck et al. (2016), the welfare loss from a supply disruption, such as that caused by mandated restrictions, can be significantly greater than the loss evaluated using standard measures of welfare. If ignored, the public may experience adverse effects due to supply restrictions that are missed in public policy discourse. These welfare consequences also explain why utilities are concerned about how the mandated 2015 restrictions in California affect their financing plans. A main contribution of this paper is to calculate the welfare loss associated with the 2015 mandated cutbacks. Specifically, the research objective of this paper is to quantify the California single family residential consumer welfare losses due to the mandatory restrictions to urban potable water use adopted in May 2015 by the SWRCB.

Our work contributes to the literature on water demand in three additional ways: (i) we estimate the annual water demand curve for the single family residential sector using monthly data, and additionally the seasonal water demand curve, which allows us to compare water price elasticities across the two demand curves; (ii) we employ new data from Southern Californian utilities across the 2004-2009 time period, so no significant extrapolation is required for the welfare loss calculation; (iii) we recognize that the SWRCB water use restrictions requires annual demand analysis. Using annual demand, the total welfare consequences of the 2015 mandate is calculated; also, we calculate welfare losses by regions. In some utility service areas, such as most of the utility service areas in the San Francisco Bay Area (Northern California), most of the water use is for indoor purposes (e.g. drinking, showering), which is more valued than outdoor purposes (such as lawn watering). Therefore, smaller percentage reductions on utilities with demand mostly for indoor water use throughout the year might result in larger welfare losses than larger percentage reductions on utilities with very high outdoor water use. Another feature of this paper, which is distinct from previous work, is applying heterogeneity in supply restrictions as defined by the SWRCB for each water utility and comparing the results to the welfare loss without considering heterogeneity in supply restrictions. Thus, we can also make empirical statements about the efficiency of the regulation ultimately adopted by the California SWRCB, particularly with regard to the assignment of the utility-specific percentage reductions.

The data used for the demand estimation includes monthly retail-level (utility-level) panel data on average water consumption per household and median tier prices between January 2004 and December 2009 for single-family residential (SFR) consumers in California. In particular, the dataset includes 90 urban water utilities from Southern California (the Los Angeles and San Diego metropolitan areas) and 21 utilities in Northern California (the San Francisco Bay Area).

The rest of the paper is organized as follows: Section 2 presents background and related literature, followed by welfare loss framework in Section 3. Section 4 presents the dataset, empirical model, and residential water demand estimation results. Section 5 discusses the welfare loss calculation results and the final Section 6 provides concluding remarks.

2. Background

Drought continued to affect California through 2015, making the last four years the driest and the hottest in the instrumental record for the State. Also, the drought situation in California has been progressively worsening over the years[1] (U.S. drought Monitor, 2016). Impacts on local communities, ecosystems, and the economy have continued to grow, including recent water use restrictions, rapid

[1] See http://droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?CA for more information.

draw down of groundwater reserves (Famiglietti, 2014; Harter and Dahlke, 2014), fallowed agricultural fields (Howitt et al., 2014). California drought has a widespread but unevenly distributed impact on different sectors and water users, including farmers, industry, cities, and natural ecosystems that depend on water quantity, timing of flows, and water quality (Gleick, 2016). The 2012-2015 drought in California is the third drought in recent Californian history (California experienced drought in 1987-1992, 2007-2009).[2]

In response to this historical drought, for the first time in state history, the Governor has directed the State Water Resources Control Board (SWRCB) to implement mandatory water reductions in urban water utilities across California to reduce statewide water usage by 25%. Under the state's mandated conservation cutback, only urban water utilities who serve more than 3,000 customers or deliver more than 3,000 Acre Foot (AF) of water per year are assigned to reduce their water supply from 8% to 36%. Based on SWRCB report, 411 urban water utilities are subject to this mandate which supplies more than 90% of urban water use in California.[3] These water utilities vary greatly in their size, organization type, water supply source, and infrastructure. Enforcement of the 2015 mandate could be difficult because of these differences. Typically, there are penalties for violating these measures. For example, one of the enforcement tools from the SWRCB has the ability to fine water utilities that do not comply up to $10,000 per day. Implementing this fine is difficult because of differences in urban water utilities revenue. Utilities that serve smaller populations have smaller revenues than those that serve larger communities (Conrad, 2013). For instance, a $10,000 per day fine for the Los Angeles Department of Water and Power (LADWP), which serves almost 4 million people, is a very small share of LADWP total revenue. However, this fine is large for the smaller utilities which serve only 3,000 customers.

In a recent paper on measuring welfare losses from urban water supply restrictions, Buck *et al* (2016) uses urban water utility-level panel data over the period of 1996-2009 to estimate the annual water demand curve in California. For the welfare loss analysis, they used 53 urban water utilities (wholesalers) in California and estimated the annual welfare loss under 10% - 30% of shortage. Their results indicate welfare losses range from $1,458 to $3,426 per acre-foot of, respectively, 10% and 30% shortage. We follow Buck et al. in framing our analysis; however, our analysis departs from their

---

[2] For more detail information about 1987-1992 drought consequences see Gleick and Nash 1991; and Nash 1993, the 2007-2009 drought see ChristianSmith et al. 2011, and the current 2012-2015 drought see Cooley et al. 2015; and Gleick 2015.

[3] A large number of very small suppliers serving less than 3,000 customers exist in California.

analysis in several essential ways. First, we estimate demand using monthly datasets which allows us to estimate seasonal demand in addition to an annual demand curve and compare water demand price elasticities across demand specifications. Second, we employ new data from 111 utilities across Southern and Northern California as opposed to Buck et al (2016) that used only 37 utilities, so no significant extrapolation is required for the welfare loss calculation. Third, we recognize that the SWRCB water use restrictions are at the water utility level. Specifically, the mandate was a percentage reduction based on average water use during summer months. In this paper, for welfare loss calculations, heterogeneity in water supply restrictions across the utilities is considered which is consistent with the 2015 governor's mandate. In summary, we bring new evidence on monthly water demand, which we use to examine heterogeneity in demand across space and season; we use this new information to conduct a welfare analysis of the mandated restrictions imposed in 2015.

3. Welfare Loss Framework with Seasonal Demand

3.1. Basic loss model

Magnitude and duration of the urban water supply disruption are two main components for measuring rate-payer welfare loss. Losses in the residential sector are usually measured by the consumers' willingness to pay to avoid water supply disruption (Jenkins et al., 2003; Brozovic et al., 2007; Wan et al., 2013; Buck et al., 2016). In this study, we adopt the approach of Brozovic *et al.* (2007) and Buck *et al.* (2016) to estimate the willingness to pay of residential end-users to avoid water supply disruption. Supply disruption magnitude in the region *i* at time *t* can be defined as:

$$z_{it} \in [0,1] \text{ where } \begin{cases} z_{it} = 0 & \textit{complete outage} \\ z_{it} = 1 & \textit{baseline level of service} \end{cases}$$

Define $f_{it}(z_{it})$ and $W_i(z_{it})$ respectively as a probability density function of water supply disruption, and consumer willingness to pay to avoid water supply disruption in region *i* at time *t*. Then, assuming *I* regions and *T* periods until the complete re-establishment of normal water supply service, the following equation gives the residential (R) welfare loss estimate:

$$W^R = \sum_{t=1}^{T} \sum_{i=1}^{I} \int_0^1 W_i(x) f_{it}(x) dx \qquad (1)$$

For a given region and time, we can compute $W_i(z_{it})$ by integrating the area under the demand curve for the supply disruption level of z_{it}. Based on this definition $W_i(z_{it})$ can be defined as:

$$W_i(z_{it}) = \int_{Q_i(z_{it})}^{Q_i^*} P_i(x)dx \qquad (2)$$

where $P_i(x)$ is residential inverse demand function in the region *i*, Q_i^* is normal water supply level prior to the supply disruption ($z_{it} = 1$), and $Q_i\ (z_{it})$ indicates the quantity of supply after a supply disruption in region *i* and time *t*.

3.2. Review of Governor's Mandate

In April 2015, Governor Brown gave an executive order to reduce water supply in response to California's severe drought conditions. In May 2015, the SWRCB adopted an emergency regulation to address the April 2015 Executive Order. The emergency regulation includes mandatory 25% statewide reduction in potable urban water use between June 2015 and February 2016. For this aim, SWRCB proposed a utility level heterogeneous conservation standard. Based on this standard, utilities who serve more than 3,000 customers or deliver more than 3,000 acre-foot of water per year are assigned to reduce their water supply between 8% and 36%, which accounts for more than 90% of California urban water use; Table 1 illustrates this program. This schedule defines nine conservation standards based on the per capita water usage during 2013 summer months (July to September). As Table 1 illustrates, Tier 9 includes the highest number of utilities (94 utilities) and tier 3 includes the lowest number of utilities (21 utilities) (SWRCB, 2015). Collectively, urban water utilities need to achieve a 25% reduction in potable water use statewide, which approximately saves 1.3 million acre-foot of water over the eight month (June- January) period.

4. Residential Water Demand Estimation

The price elasticity of water demand is one of the main components for measuring welfare losses due to the urban water supply disruptions. The price elasticity of demand is estimated for average single family residential monthly water demand using data on monthly consumption and the number of accounts in the single family residential sector.

Arbués et al. (2003) overviewed the problems arising in estimating water demand in the block pricing structure. This study analyzed different specifications of water demand models, functional forms, different data sets, selection of the variables, and type of price specification. Using household level data allows for consideration of household level variations in the water price (Hewitt and Hanemann, 1995; Pint, 1999; Arbués et al., 2004) and clear modeling of the choice of consumption block (Hewitt and Hanemann, 1995). However, in this study, like most other empirical works on water demand (for example, Buck *et al.* 2016), we have utility aggregated level data. There are many studies internationally (e.g., France (Nauges and Thomas 2000; Nauges and Thomas 2003), Germany (Schleich and Hillenbrand 2009), Italy (Mazzanti and Montini 2006), Spain (Martinez-Espineira 2002; Martinez-Espineira 2007)), and also in the United States (Hewitt and Hanemann 1995; Olmsted, Hanemann, and Stavins 2007; Pint 1999; Gaudin 2006) which estimated water demand in the residential sector. We used these studies to frame our demand model in terms of specification, functional form, and choice of control variables.

In terms of functional form, we used the log-log model, where all the variables enter into the regression equation in the logarithmic form. This functional form was used most frequently in the previous studies, Mazzanti and Montini (2006), Olmstead *et al.* (2007), and Frondel and Messner (2008), in which estimated parameters can be interpreted as the elasticity of demand.

Let q_{it} denote household's *i* water consumption during month *t* and p_{it} be the marginal price of water. Suppose that the household has a quasi-linear utility function and responds to a water price changes with a constant elasticity β_1 . Then, the demand function can be described as:

$$\ln(q_{it}) = \beta_0 + \beta_1 \ln(p_{it}) + \eta_{it} \qquad (3)$$

In equation (3) we assumed quasi-linear utility function which eliminates income effects from price changes. Also, using this equation, we assumed that price elasticity of the water demand is constant over time and over households. Lastly, we assumed water demand only responds to the current price and there is no lagged effect. The main problem of demand estimation using equation (3) is simultaneity problem between price and quantity. As discussed in Buck *et al.* (2016) this problem is not the concern in studies like this one because for most of the urban water utilities in California, water prices are set by local government and are not determined by the market supply and demand equilibrium. Following Buck *et al.* (2016) and Olmstead (2009), we argue that our basic model does not suffer from this form of simultaneity bias.

It is apparent that using panel data has several advantages over cross-sectional data (Billings and Agthe, 1980; Gaudin, *et al* 2001; Martinez- Espeneira, 2003). The specification in equation (3) does not allow us to take advantage of the panel data and control for the time-invariant unobservables such as climate. Using urban water utility fixed effects can control for this type of unobserved variable.

Using Ordinary Lease Squares (OLS) to estimate the equation (3) produces an inconsistent estimate of β_1. Many urban water utilities use increasing block pricing (IBP) schedules so that p_{it} is a function of q_{it}. In fact, under IBP schedule, η_{it} is positively correlated with p_{it} . For example, if a household has a positive shock in η_{it} that is not observable to the researchers, the household will locate in the higher tier of its IBP schedule. This simultaneity bias is exactly the same problem as the identification problem in the income tax literature that usually involves estimation under a progressive income tax schedule and labor supply literature (Auten and Carroll, 1999; Saez, Slemrod, and Giertz, 2012; Ziliak and Kniesner, 2005; Hewitt and Hanemann, 1995). To address the simultaneity bias, we used price on the median tier of each utility (by year) as a marginal price measure.

4.1. Econometric Specification

To estimate a demand curve we will use a fixed effects estimator. The base equation that we intend to estimate is reported in equation (4):

$$\ln(q_{imt}) = \beta_1 \ln(P_{imt}) + \beta_2 \ln(W_{imt}) + \mu_i + \theta_y + \tau_m + u_{imt} \quad (4)$$

where q_{imt} is the average single family residential consumption inutility service area *i* in year *t* and month *m*; P_{imt} is the marginal price per hundred cubic foot (CCF) on the median tier of the price schedule; W_{it} is a vector of precipitation and temperature measures; μ_i is a utility service area fixed effect; θ_y is a year fixed effect; τ_m is a month fixed effect, and u_{imt} captures all unobserved factors affecting the dependent variable. Spatial heterogeneity is modeled by interacting price with median household income and region dummy indicator. Seasonal heterogeneity is modeled by interacting price with summer months' dummy. Summer is defined by SWRCB as July, August, and September months. Finally, spatial and seasonal heterogeneity is modeled by interacting price with summer and region dummy indicators.

4.2. Data

The data used in this study includes monthly retail level panel data on average water consumption and median tier price, between January 2004 and December 2009, for single family residential (SFR) consumers in California. In particular, the dataset includes 90 urban water utilities from Metropolitan Water District of Southern California (MWD) and 21 utilities in the San Francisco Bay Area. Monthly consumption and median tier prices for water utilities in the San Francisco Bay Area were obtained from the Bay Area & Water Supply Conservation Agency Annual Surveys from 2004-2009; similar data for water utilities in the MWD service area were obtained by directly contacting each individual water utility. In total, the sample contains 5,573 observations from 111 urban water utilities.

4.2.1.Water Consumption Data

The dependent variable is average water consumption in hundreds of cubic foot (CCF) per household per month from the utility in a particular service area. In particular, SFR per household monthly consumption for each water utility calculated by dividing the total SFR consumption for each month by the number of SFR metered accounts in that specific water utility. Households water demand is composite including direct demand (for drinking) and indirect demand as a complement for different uses (for example, cooking, washing, and also outdoor uses such as gardening) (Höglund, 1999; Schleicha, and Hillenbranda, 2009). Water consumption data in this study is aggregated and does not differentiate between the two types.

Table 2 provides descriptive statistics for water consumption by region and season in 2009. We defined summer months (July, August, and September) as the arid season and non-summer months as the wet season. Water consumption varies by season in both regions. Water consumption in sample utilities located in Southern California is, on average, 1.6 times water consumption in sample utilities located in Northern California. This corresponds to our initial claim, since Southern California tends to have larger lot sizes and somewhat drier conditions, which leads to more outdoor water use and higher overall consumption.

4.2.2. Water Price Data

The utilities in the regression sample use different pricing structures, including uniform pricing and IBP schedule. We assume that the equilibrium price of water for the households in each utility service area is equal to the price per hundreds of cubic foot (CCF), on the median tier of the utility's IBP structure. Figure 1 plots standard deviation of price by urban water utilities according to region. This figure indicates the standard deviations of price within each utility; the median of these is $0.22 for the sample utilities in the Northern California (the unweighted average price is $2.63 per CCF), and the median of these is $0.11 for the sample utilities in the Southern California (the unweighted average price is $1.53 per CCF). This information supports our empirical research design which employs a utility fixed effects estimator. In particular, we are using the year to year variation of the price within a utility to identify the effect of price on water consumption.

4.2.3. Household Characteristics and Weather

We used 2000 Census tract data to obtain median household income and demographic information, including household size and lot size as a proxy for consumer preferences. These variables were generated using the intersection between utility specific borders with the 2000 Census tract borders. Specifically, we used household weighted-average of these variables in the empirical model for demand estimation. In addition, we include weather drivers of residential demand; specifically, variables measuring precipitation and temperature, which obtained from the PRISM (Parameter-elevation Regressions on Independent Slopes Model) group.

4.3. Estimation Results

We estimated the water demand model using various specifications, which is reported in Table 3. In column (1) we present a simple cross-sectional specification with Ln (Price) and year fixed effects. The estimation results suggest negative but high (-0.43) elasticity of water demand. As explained before, estimation results using cross-sectional data has several disadvantages including omitted variable bias.

In order to account for retail level time-invariant unobservable variable, we use utility fixed effects in the model; the estimation results are reported in Column (2) of Table 3. The estimated price elasticity of demand is (-0.17). Additionally, we used county specific linear and quadratic annual time trends. This helps to capture the time-variant county level unobservables such as conservation efforts. Most of the urban water utilities in one county share same conservation programs; using county specific linear and quadratic time trends can control for these types of unobservables. Column (3) in Table 3 shows the results when we include county specific linear and quadratic time trends. Implied price elasticities in this specification is larger than pervious specification (-0.18) with slightly larger standard errors. As expected, we have a small downward bias in the estimated elasticity when we do not use county specific linear and quadratic time trends.

In Column (4) of the same table, we used month fixed effects and weather controls. Because price variation within a utility is annual, omitting month fixed effects should not introduce bias in the elasticity estimation. In fact, there is not a month level unobservable that can affect price variation. Using month fixed effects should help improve the precision of the estimation with tighter standard errors since water consumption is seasonal. New estimated elasticity is (-0.19) and, as we expected, associated standard error with this estimation is smaller than previous.

In order to investigate the interaction between price elasticity of demand and income, we use a simple interaction model in which we interact median tier price (Ln (Price)) with median household income (Ln (Income)). This interaction term captures the extent to which the responsiveness of households to price increases or decreases as income changes. Because the price elasticity of demand is negative, a positive coefficient of the interaction term indicates a decrease in the price response as income increases. In Column (1) of Table 4, we used the same specification as Column (4) of Table 3 and the only difference is that we added interaction of median tier price with median household income to allow for the household heterogeneity. Results indicate that own price elasticity in an urban water utility with a median household income of $65,000 would be -0.15 ($65,000 is the weighted median income by using an average number of households in each utility service area as a weight).

There is evidence that summer water demand is inherently different and lumping winter and summer demand together is not appropriate (Dalhuisen et al., 2003; Espey et al., 1997; Bell and Griffin, 2011). To differentiate between summer and non-summer water demand we used the interaction between summer demand and median tier water price. The inclusion of this interaction term permits us to statistically detect the existence of utility-level variation in average price responsiveness based on the summer versus non-summer months. The results of this specification is reported in Column (2) of Table 4. As expected, the coefficient of the price and summer interaction term is negative, which means water demand in the summer is more elastic. In fact, outdoor water use is higher in the summer, so it is not surprising that households are more sensitive to price changes. Implied price elasticity of demand for median income ($65,000) in the summer is (-0.18) and for non-summer is (-0.14).

In our 7th specification, we account for the spatial heterogeneity of elasticity of demand. As explained in the data section, per household water consumption in the sample utilities from Northern California is lower than sample utilities from Southern California. Outdoor water use (e.g. gardening) is higher in Southern California. Also, households in Southern California have larger lot size and as previous research shows lot sizes has a positive effect on water consumption. Column (3) of Table 4 has the same specification as Column (2) of the same table except that in Column (3) an interaction term between price and an indicator for the Southern California (MWD) urban water utilities is included. We expect to have a negative coefficient for this interaction term because of higher outdoor water use in Southern California. For this reason, we expect households in Southern California to be more sensitive to price change than Northern Californian households. The results indicate that this interaction term has a negative sign, but it is not statistically significant.

One potential reason for the imprecision is that there may exist multicollinearity between (Ln (Price) Summer) and (Ln (Price) MWD). This can happen because households in MWD have higher water consumption in the summer than non-summer months versus households in Northern California, which have approximately similar water consumption in the summer and non-summer months. To account for these potential issues, we defined specification number (8). There are only two differences between specification number (7) and (8) are that: (i) the interaction between price and MWD is excluded, and (ii) the interaction between price, summer, and MWD is included. Results for this specification are reported in Column (4) of Table 4. Using this specification, we can allow for income, regional, and seasonal heterogeneity in the price elasticity. The results of this specification show that interaction between summer, MWD, and price is negative and statistically significant. This indicates that households in Southern California in the summer season have the largest price responsiveness compared to the other households and seasons. Also, interaction of summer and price is not significant which suggests there is not heterogeneity in price elasticity of demand for the households in Northern California with respect to the season (similar price elasticity of demand in summer and non-summer for the Northern Californian households means that these households value water similarly in different seasons). There are two main reasons that this may be happening. The first reason is that there is not a large difference between summer and non summer water use. In fact, Northern California outdoor water use is small. The second reason is that even though households have outdoor water use in the summer (but a small amount compared to Southern California), outdoor water usage may be for watering asset-type outdoor plants (such as palm or fruit trees). This may also explain why results indicate that Northern Californians have similar price-responsiveness throughout the year.

A summary of implied price elasticities by season and region are reported in Table 5. Heterogeneity in price elasticity of the water demand is observed across seasons (summer vs. non-summer) for Southern California and regions (MWD vs. Northern California). Water demand in MWD is more responsive to price during summer. Water demand in MWD in summer is associated with the mean price elasticity of (-0.33), demand gets less price responsive in MWD in non-summer (-0.19). Northern California has the least price responsive water demand (-0.13) which is not varying by season.

Figure 2 presents estimated price elasticity of demand for MWD and Northern California during summer and non-summer. In MWD urban water utility service areas, heterogeneity in price elasticity of water demand is larger in summer and households are more sensitive to price changes in summer, as well. However, for the Northern California urban water utilities, heterogeneity of price elasticity is similar in summer and non-summer. Generally, price elasticity of water demand is smaller for Northern California than Southern California. Estimated price elasticities for the sample utilities represents that summer and non-summer elasticities are similar for urban water utilities located in the San Francisco Bay Area. This difference becomes larger for the utility service areas located in Southern California. Southern Californians consume more water in summer (mostly for outdoor use purposes such as watering lawns) than they consume in non-summer months. Prior studies used the difference between summer and winter consumption as outdoor water use (Mansur and Olmstead, 2012; Olmstead et al., 2007).

5. Welfare Results

In this section, we quantify welfare loss due to the Governor's mandate in Northern and Southern California. First, we parametrized the loss function. Next, we describe the data and different scenarios which are used to estimate welfare loss. Finally, we present the results of welfare loss.

5.1. Parameterizing the Loss Function

Following Buck *et al.* (2016) and Brozovic *et al.* (2007) we assumed constant elasticity of demand and estimate the single family residential water demand elasticities for each urban water utility using the following equation:

$$P_i = A_i Q_i^{\frac{1}{\varepsilon_i}} \quad (i = 1,2,3, \dots, n) \qquad (6)$$

where, A_i is a constant and ε_i is the elasticity of water demand in utility *i*. Assuming P_i^* and Q_i^* are the price and quantity of water consumption by households, respectively, in urban water utility service area *i*, prior to the mandatory supply restriction.

Assuming water supply restriction at time *t* for urban water utility *i* is given by $Q_i(z_{it}) < Q_i^*$ we can define water supply shortage in terms of percentage for urban water utility *i* at time *t* as following:

$$Q_i(z_{it}) = (1 - r_{it})Q_i^* \qquad (7)$$

Using equation 6 and 7, we can estimate consumer willingness to pay to avoid supply restriction z_{it} (Welfare loss due to the shortage z_{it}) at time *t* for urban water utility *i* using following equation:

$$W_i(z_{it}) = \int_{Q_i(z_{it})}^{Q_i^*} P_i(Q)dQ = \int_{Q_i(z_{it})}^{Q_i^*} A_i Q_i^{\frac{1}{\varepsilon_i}} dQ = \frac{\varepsilon_i}{1+\varepsilon_i} P_i^* Q_i^* \left[1 - (1 - r_{it})^{\frac{1+\varepsilon_i}{\varepsilon_i}}\right] \qquad (8)$$

Note that urban water utility's total cost of service is the sum of fixed cost (such as infrastructure costs, repair, and maintenance, administrative expenses, etc.) and variable cost (e.g., energy and chemical costs of treating water) which depend on the amount of water delivered to the customers. Supply restriction reduces service variable costs simply because urban water utility *i* supplies $Q_i(z_{it}) < Q_i^*$. The measure of welfare loss indicated in equation (8) does not account for the avoided costs of service delivery during a supply shortage.

Assuming the marginal cost of service delivery is C_i , equation (8) becomes as follows:

$$W_i(z_{it}) = \frac{\varepsilon_i}{1+\varepsilon_i} P_i^* Q_i^* \left[1 - (1 - r_{it})^{\frac{1+\varepsilon_i}{\varepsilon_i}}\right] - \int_{Q_i(z_{it})}^{Q_i^*} C_i(x)dx \qquad (9)$$

Assuming a flat marginal rate curve, we can rewrite the welfare loss function as follows:

$$W_i(z_{it}) = \frac{\varepsilon_i}{1+\varepsilon_i} P_i^* Q_i^* \left[1 - (1 - r_{it})^{\frac{1+\varepsilon_i}{\varepsilon_i}}\right] - r_{it} Q_i^* C_i \qquad (10)$$

Under the assumption of the flat marginal cost curve, the average loss per unit of shortage will be as follows:

$$W_i/Q_i^* r_{it} = \frac{\varepsilon_i}{1+\varepsilon_i} P_i^* \left[1 - (1 - r_{it})^{\frac{1+\varepsilon_i}{\varepsilon_i}}\right] / r_{it} - C_i \quad (11)$$

Based on the parameters in equation (11), welfare loss is a function of initial water price prior to the supply restriction in urban water utility *i* at time *t*, the variable cost of service, and elasticity of demand in service area *i*. Heterogeneity in the estimation of the welfare loss in this paper comes from differences in price, and price elasticity across the urban water utilities. Furthermore, water supply shortage heterogeneity across the utilities and regional differences are other sources for welfare loss heterogeneity.

5.2. Data for Calculation of Losses

Using equation (11) and data from 53 urban water utilities in California, including 27 utilities in the San Francisco Bay Area and 26 utilities in Southern California, welfare loss due to the supply shortage is calculated. In order to calculate total welfare loss due to the supply shortage, we can aggregate welfare loss in each of these regions. Based on equation (11) we need baseline prices, baseline quantity of demand, the supply shortage, the price elasticity of demand, and the marginal cost of service delivery. Data is available publicly for all of the above information except for the price elasticity of demand and the marginal cost of service delivery.

Because of data restrictions for 2013, we used 2009 as a baseline in the welfare loss analysis. Generally, water demand is decreasing over time and using 2009 as a baseline cannot introduce upward bias in welfare losses calculations. Single family residential demand data is obtained through the Bay Area Water System and Conservation Association (BAWSCA) Annual Survey from FY 2009-2010, and from estimates provided by SFPUC and MWD. For the San Francisco Bay Area utilities that belong to BAWSCA, the price data is the year 2009 median tier rate reported in the BAWSCA survey; prices for the other utilities are obtained from their websites or through a telephone interview. In the case of wholesale utilities, such as many of the utilities belonging to the MWD, no single median tier price exists because they sell their water to multiple local utilities who set their own rates. Thus, for each wholesale utility we collected rate information on every single local utility within the wholesale utility, and then quantity-weighted average of the median tier price is calculated. Figure 3 presents the range of median tier prices (converted to price per acre-foot of water) for these 53 urban water utilities. Mean, minimum and maximum prices in Northern California utilities are $1,485, $709, and $2,755, respectively; 26 utilities are from Southern. Mean, minimum and maximum prices in Southern California utilities are $1,157, $614, and $2,156, respectively.

The demand estimation suggests that the price elasticity of water is significantly different across utilities throughout the state. Based on column (1) in Table 4 (specification number 5), price elasticity for each of the 53 utilities is estimated. The range of elasticities is displayed in Figure 4. Mean, minimum and maximum estimated price elasticities in Northern California utilities are -0.14, -0.27, and -0.1, respectively; mean, minimum, and maximum estimated price elasticities in Southern California utilities are -0.25, -0.45, and -0.1, respectively. We truncated estimated elasticities at -0.1. Based on equation (11), more inelastic demand causes larger welfare losses because of higher marginal value of water in these more inelastic households. Based on the mandate, water utilities in Southern California are subject to higher cutbacks in water consumption, but welfare losses may be smaller in this region. Although cutbacks in Northern California are smaller we might observe larger welfare losses in this region because of very inelastic demand.

We estimate welfare losses for two alternative regulatory scenarios. One, a 25% uniform reduction in water supply referencing 2009 as a base. Under this scenario, each urban water utility needs to cut back 25% of aggregated water supply between Jun-January in reference to the 2009 level. However, only annual levels of the water consumption data for these 53 utilities were available. To adjust the water consumption for 8 months alone, we multiplied total consumption in 2009 for each utility by 0.75. This scenario is representative of naive policy option in which policymakers does not differentiate between values of marginal unit of water in different utilities. For example, residents in utility service areas with high outdoor water consumption should cutback a similar percentage as residents in utility service areas with low outdoor water consumption. We expect to have high inefficiencies in terms of welfare losses using this scenario (large per acre-foot welfare losses). Two, in the second scenario, we used the SWRCB utility level conservation standard data in which we can observe heterogeneity in a supply shortage across the utilities. For simplicity, this scenario is named SWRCB conservation program from this point in the paper. Based on the mandate, urban water utilities in the sample are assigned to reduce their total consumption between June-January between 4% and 36%. Conservation standards for the utilities are obtained from the SWRCB website. In the case of wholesale utilities, such as many of the utilities belonging to MWD, no single conservation standard exists because they sell their water to multiple local utilities who have their own conservation standard from SWRCB. Thus, for each wholesale utility we collected conservation standard information on every single local utility within the wholesale utility, and household-weighted average conservation standard is calculated.

Figure 5 is a visual illustration of the 53 utilities shares for each mandated cutback percentage by region. As shown in this figure, utilities in Northern California are mostly in tier 2, 3, and 4 and utilities in Southern California are in higher tiers (6, 7, 8, and 9) of the conservation program. Utilities in Northern California (on average required to cut back water supply by 15%). However, utilities in Southern California on average were required by the SWRCB mandate to cut back supply by 23%.

Using equation (11), the marginal cost of service delivery is required to be able to conduct welfare loss analysis. We assumed marginal cost of service delivery of $193 per acre-foot. Also, for welfare loss calculations we assumed heterogeneous price elasticities, heterogeneous prices, and a portion of fixed cost in volumetric price. Buck et al. (2016) demonstrated that ignoring the fact that urban water utilities in California use non-marginal pricing will affect the welfare loss calculations. For example, they found that 10% shortage in water supply without assumption of non-marginal pricing will underestimate welfare loss by approximately 31%. This percentage increases as shortage in water supply increases, for instance they found in a case of 30% shortage in water supply, bias in welfare loss calculation increases to 68%.

5.3. Welfare Consequences of the Mandate

To overview the big picture, first we present the calculated total welfare losses due to the 25% shortage and the SWRCB conservation program in California which is reported in Table 6. Total welfare loss in California is $952 million dollars with average per acre-foot loss of $3,796. However total loss with the SWRCB conservation program is $843 million with average per acre-foot loss of $3,771. We cannot compare the total losses because of the differences in the amount of shortage in two scenarios; however, average losses are comparable. As Table 6 illustrates, average per acre-foot loss under the SWRCB conservation program is less than average per acre-foot loss under 25% uniform shortage. This means that the SWRCB conservation program is generally more efficient than uniform cutback policy for water conservation. Total water saved by single family households in California under the 25% uniform cutback is 404,000 acre-foot, and under the SWRCB conservation program total water saved decreases to 359,000 AF.

Table 7 presents the result of welfare loss calculations in Southern and Northern California. For the San Francisco Bay Area (Northern California), total losses are estimated to be $147 million under 25% uniform cutback and $130 million under the SWRCB conservation program. For Southern California utilities, total losses are estimated to be $805 million under 25% uniform cutback policy and $713 million under the SWRCB conservation program. Larger total losses in Southern California are due to the larger population in this region than San Francisco Bay Area. To facilitate comparison between Southern California and San Francisco Bay Area welfare losses due to the supply shortage, we calculated the average losses per acre-foot of shortage and results are presented in Table 7. Results indicate that per acre-foot loss in Southern California is smaller in both scenarios; however, difference between per acre-foot losses is larger under the SWRCB conservation program than under the 25% uniform cutback. This is a signal that the SWRCB conservation program is inefficient in the San Francisco Bay Area. To show this, we compared losses per acre-foot of shortage under two scenarios only in the San Francisco Bay Area. Results indicate that under 25% shortage average per acre-foot loss is $4,424 and under the SWRCB conservation program per acre-foot loss is $6,132. It is important to mention that under 25% shortage total water saved in San Francisco Bay Area utilities is 33,000 acre-foot, but under the SWRCB conservation program, on average San Francisco Bay Area utilities save 15% water which is equal to 21,000 acre-foot. This presents inefficiency in the distribution of the conservation tiers between the San Francisco Bay Area utilities. Overall, the SWRCB conservation program saves less water in the San Francisco Bay Area, but per acre-foot average loss is higher.

In Southern California average loss per acre-foot of shortage under the 25% uniform cut back is $2,171 and under the SWRCB conservation program this reduces to $2,113. Total water saved by Southern California utilities under the 25% uniform cut back is 371,000 acre-foot, and under the SWRCB conservation program these utilities save on average 23%, which is equal to 337,000 acre-foot of water. Unlike the San Francisco Bay Area utilities, we observe some efficiency gain under the SWRCB conservation program for Southern California utilities; however, this efficiency gain is small.

Figure 6 illustrates average per acre-foot welfare loss heterogeneity in the sample urban water utilities by region. Heterogeneity in average welfare loss per acre-foot of shortage is larger for the utilities in the San Francisco Bay Area under the SWRCB conservation program than 25% uniform shortage. For the Southern California utilities, heterogeneity in average welfare loss per acre-foot of shortage under the SWRCB conservation program is larger than the 25% uniform cutback.

The second and fourth rows of Table 7 indicate the 95% confidence interval for each estimate. These confidence intervals reflect the estimated variability in the price elasticities of demand recovered from the regression analysis. Due to non-linearities of the price elasticity in the expression for aggregate welfare losses, the confidence intervals for welfare losses are bootstrapped by cluster (urban water utility) in favor of confidence intervals based on analytic standard errors.

The fifth row of each panel illustrate the average household's willingness-to-pay (WTP) to avoid supply shortage under each scenario. Estimated monthly WTP per household to avoid the 25% shortage is $40 in Northern California and $28 in Southern California. Northern Californian households' WTP to avoid 25% uniform supply shortage is more than Southern Californian households'. Under the SWRCB conservation program estimation results indicate that households' WTP in Northern California is $36 per month to avoid the mandate and households' WTP in Southern California is $25 per month. The last row of both panels illustrate households' WTP measure in terms of percentage increase in expenditures on the volumetric rate component of the household's monthly water bill. Households in Northern California have WTP in terms of increase in monthly water bills between 78% and 87%, depending on the scenario. However, households in Southern California have WTP in terms of increase in the monthly bills between 35% and 51%.

5.4. Comparison of the Results

Comparing estimated demand elasticities shows that demand in summer is less inelastic than demand in non-summer in Southern California. This is because outdoor water use in Southern California is higher in summer, which makes consumers more responsive to price changes. However, we found demand elasticity in summer and non-summer in Northern California are similar. We argue that this is happening because outdoor water use in Northern California is more for the asset type trees (such as palm). There is a possibility that people in Northern California already are using outdoor water for keeping a minimum amount of lawns green or water efficient green spaces alive than Southern California, where people have larger spaces of lawns or outdoor water use is not as efficient as Northern California.

We also found that Southern California is more responsive to price than Northern California. This finding is consistent with previous findings in Buck et al. (2016). However, using monthly level data on the water consumption we estimated more precise confidence intervals for the welfare losses than Buck et al. (2016), though the precision gains are not consequential. For example, in the San Francisco Bay Area they estimated $5,414 million for average per acre-foot loss in the case of 30% shortage with confidence interval of [$2,944-$10,795]. Using the same set of assumptions and information, except using elasticities estimated with monthly data sets, our estimation of average per acre-foot loss due to 30% shortage is $5,772 with a confidence interval of [$2,091-$6,635].

Comparing different policy options to cut back water supply in California indicates that water supply shortages in Northern California causes larger per acre-foot welfare losses than the same shortage in Southern California regardless of the policy scenarios. This is happening because of smaller outdoor water use share in Northern California and approximately uniform water use during different months in Northern California. In other words, the value of one unit of water in Northern California is higher because they need to cut back indoor water uses (Southern Californians can cut back outdoor water uses) and it is approximately the same during summer or non-summer seasons because they have relatively uniform water consumption.

5.5. Cost of Governor's Mandate

In this section we summarize preliminary estimates on the cost of the 2015 Governor's mandate. Per acre-foot single family residential welfare loss is higher in Northern California than Southern California, even though cutbacks in this region are lower. Comparing welfare loss based on the 25% uniform cutback (first scenario in Table 7) with welfare loss based on the SWRCB conservation program (second scenario in Table 7), we observe that the loss under uniform cutback is smaller. This is a signal that the SWRCB conservation program is not efficient, at least in the Northern California region.

The aggregate cost of the governor's mandate is $843 million. This mandate costs $130 million in the San Francisco Bay area and $713 million in Southern California. To present this information differently, households' WTP in Northern California is $36 per month to avoid this mandate. These households are willing to see an increase in their water rates by 78% (almost double the water rate). Households in Southern California have a WTP of $25 per month to avoid this mandate; they are willing to see a 38% increase in the water rate to avoid the mandated cutbacks.

6. Concluding Remarks

Californians are experiencing the worst drought in their history. According to the U.S. Drought Monitor, more than 50% of the state is in “extreme” drought with more than 30% in “exceptional” drought.[4] In response to these conditions, the California Governor, Jerry Brown, issued an Executive Order mandating a statewide reduction in water use for the first time with the aim of 25% reduction in water use from 2013 levels. For the implementation of the Governor’s mandate the SWRCB grouped urban water utilities into nine tiers with conservation standard between 8% and 36%.

In this paper, we used monthly data from 2004-2009 on 111 utilities to estimate demand elasticity of water based on region and season. A fixed effects model is used to estimate the price elasticity of water demand. Estimated price elasticities are used to recover an estimate of the welfare consequences of the 2015 California drought mandate. Our empirical results indicate that there are variations in price elasticity of demand based on the region and season. Estimated elasticities for the sample utilities in Northern California are between -0.27 and -0.1 throughout the year; however, for the sample utilities in Southern California, estimated elasticities are between -0.61 and -0.1 in summer and -0.46 to -0.1 in non-summer. These results suggest variations in price elasticities based on the region and season.

We used estimated elasticities to recover welfare losses in California using 53 utilities. To calculate welfare losses due to the supply disturbance, two different policy options are defined, including (i) 25% uniform shortage across the utilities in an 8-month period (June- January), and (ii) utility specific mandated conservation based on the SWRCB program in an 8-month period (June-January). According to the estimated results, per acre-foot welfare loss is lowest under the SWRCB conservation program in Southern California (suggesting efficiency gains due to the mandate) and is highest under the SWRCB conservation program in Northern California (suggesting efficiency losses due to the mandate).

[4] For more information see: http://droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?CA

References

Agthe, Donald E, and R Bruce Billings. 1980. "Dynamic models of residential water demand." Water Resources Research no. 16 (3):476-480.

Arbués, Fernando, Ramón Barberán, and Inmaculada Villanúa. 2004. "Price impact on urban residential water demand: a dynamic panel data approach." Water Resources Research no. 40 (11).

Arbués, Fernando, Marıa Ángeles Garcıa-Valiñas, and Roberto Martınez-Espiñeira. 2003. "Estimation of residential water demand: a state-of-the-art review." The Journal of Socio-Economics no. 32 (1):81-102.

Auten, Gerald, and Robert Carroll. 1999. "The effect of income taxes on household income." Review of Economics and Statistics no. 81 (4):681-693.

Billings, R Bruce, and Donald E Agthe. 1980. "Price elasticities for water: a case of increasing block rates." Land Economics no. 56 (1):73-84.

Brent, Daniel A. 2013. "Estimating Water Demand Elasticity at the Intensive and Extensive Margin: The Role of Landscape Dynamics." Department of Economics, University of Washington, Working paper. Residential water management no. 125.

Brozović, Nicholas, David L Sunding, and David Zilberman. 2007. "Estimating business and residential water supply interruption losses from catastrophic events." Water Resources Research no. 43 (8).

Buck, Steven, Maximilian Auffhammer, Stephen Hamilton, and David Sunding. 2015. Measuring the Welfare Losses from Urban Water Supply Disruptions.

Cameron, Adrian J, David A Crawford, Jo Salmon, Karen Campbell, Sarah A McNaughton, Gita D Mishra, and Kylie Ball. 2011. "Clustering of obesity-related risk behaviors in children and their mothers." Annals of epidemiology no. 21 (2):95-102.

Conrad, Esther. 2013. "Preparing for New Risks: Addressing Climate Change in California's."

Dalhuisen, Jasper M, Raymond JGM Florax, Henri LF De Groot, and Peter Nijkamp. 2003. "Price and income elasticities of residential water demand: a meta-analysis." Land Economics no. 79 (2):292-308.

Espey, Molly, James Espey, and W Douglass Shaw. 1997. "Price elasticity of residential demand for water: a meta-analysis." Water Resources Research no. 33 (6):1369-1374.

Famiglietti, JS. 2014. "The global groundwater crisis." Nature Climate Change no. 4 (11):945-948.

Frondel, M, and M Messner. 2008. Price perception and residential water demand: evidence from a German household panel. Paper read at 16th Annual Conference of the European Association of Environmental and Resource Economists in Gothenburg.

Gaudin, Sylvestre. 2006. "Effect of price information on residential water demand." Applied economics no. 38 (4):383-393.

Harter, Thomas, and H Dahlke. 2014. "OUTLOOK: Out of sight but not out of mind: California refocuses on groundwater." California Agriculture no. 68 (3):54-55.

Hewitt, Julie A, and W Michael Hanemann. 1995. "A discrete/continuous choice approach to residential water demand under block rate pricing." Land Economics:173-192.

Howitt, Richard, Josué Medellín-Azuara, Duncan MacEwan, Jay Lund, and Daniel Sumner. 2014. "Economic analysis of the 2014 drought for California agriculture." Center for Watershed Sciences, University of California, Davis.

Mansur, Erin T, and Sheila M Olmstead. 2012. "The value of scarce water: Measuring the inefficiency of municipal regulations." Journal of Urban Economics no. 71 (3):332-346.

Martinez-Espineira, Roberto. 2007. "An estimation of residential water demand using co-integration and error correction techniques." Journal of Applied Economics no. 10 (1):161.

Martínez-Espiñeira, Roberto. 2002. "Residential water demand in the Northwest of Spain." Environmental and Resource Economics no. 21 (2):161-187.

Mazzanti, Massimiliano, and Anna Montini. 2006. "The determinants of residential water demand: empirical evidence for a panel of Italian municipalities." Applied Economics Letters no. 13 (2):107-111.

Nauges, Céline, and Alban Thomas. 2000. "Privately operated water utilities, municipal price negotiation, and estimation of residential water demand: the case of France." Land Economics:68-85.

Nauges, Céline, and Alban Thomas. 2003. "Long-run study of residential water consumption." Environmental and Resource Economics no. 26 (1):25-43.

Olmstead, Sheila M. 2009. "Reduced-form versus structural models of water demand under nonlinear prices." Journal of Business & Economic Statistics no. 27 (1):84-94.

Olmstead, Sheila M, W Michael Hanemann, and Robert N Stavins. 2007. "Water demand under alternative price structures." Journal of Environmental Economics and Management no. 54 (2):181-198.

Olmstead, Sheila M, and Robert N Stavins. 2009. "Comparing price and nonprice approaches to urban water conservation." Water Resources Research no. 45 (4).

Pint, Ellen M. 1999. "Household responses to increased water rates during the California drought." Land Economics:246-266.

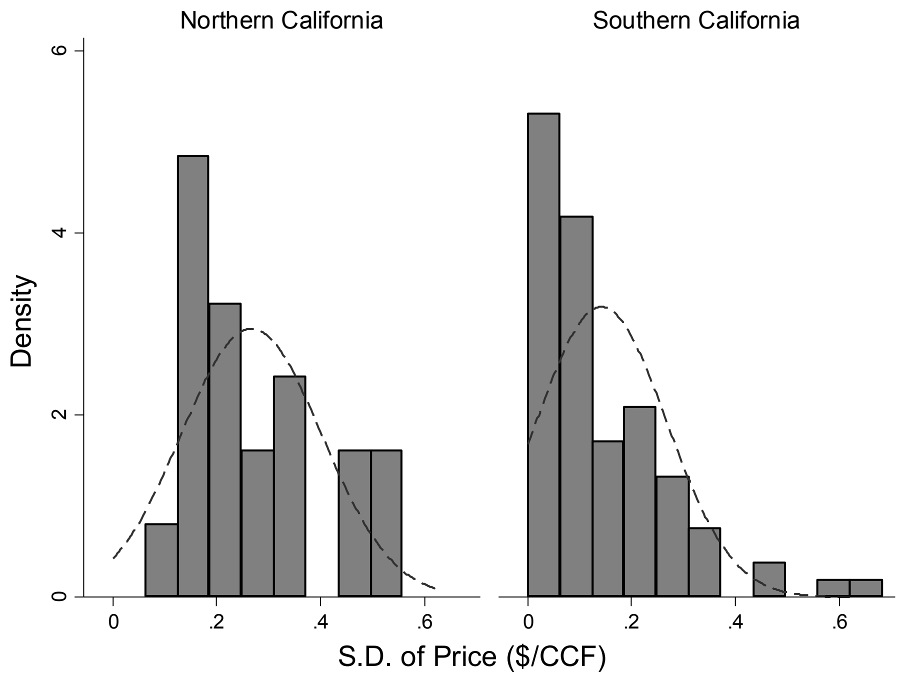
Saez, Emmanuel, Joel Slemrod, and Seth H Giertz. 2012. "The elasticity of taxable income with respect to marginal tax rates: A critical review." Journal of Economic Literature:3-50.

Schleich, Joachim, and Thomas Hillenbrand. 2009. "Determinants of residential water demand in Germany." Ecological economics no. 68 (6):1756-1769.

Ziliak, James P, and Thomas J Kniesner. 2005. "The effect of income taxation on consumption and labor supply." Journal of Labor Economics no. 23 (4):769-796.

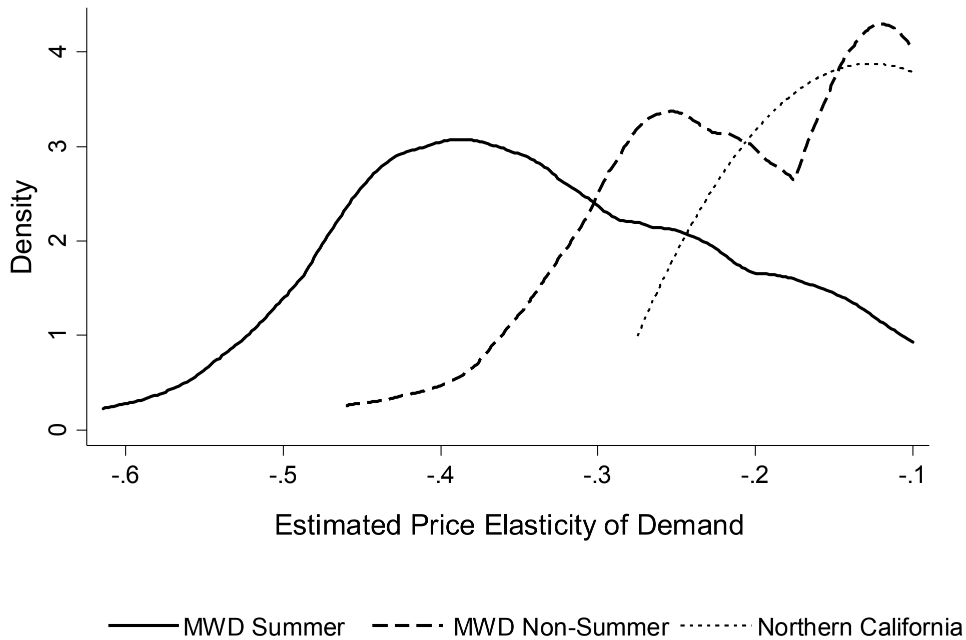
Figures and Tables

Figure 1: Standard Deviation of Price per CCF across Water Utilities from 2004-2009 by Region



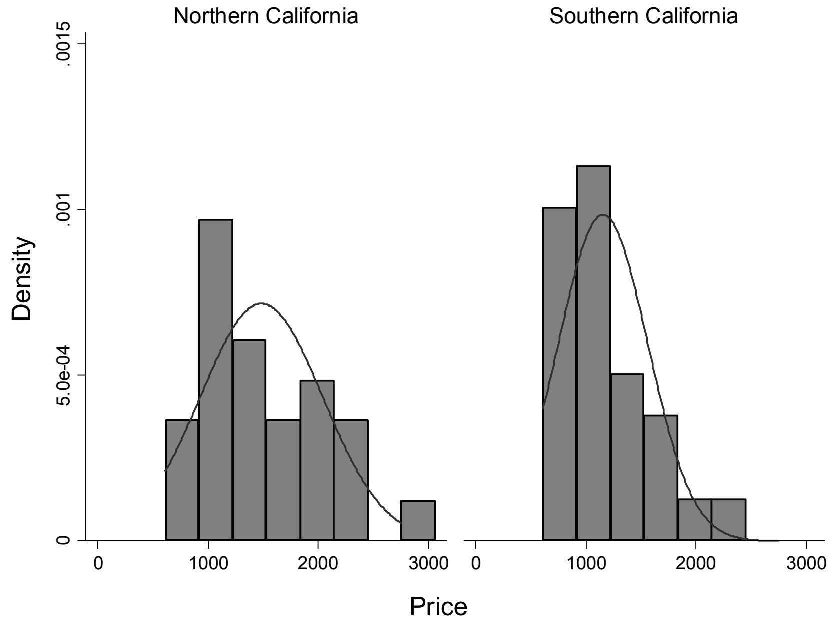
Note: Unweighted average price is $2.63, and $1.53 respectively, for sample utilities in the Northern and Southern California. Median within utility standard deviation of price is $0.22 and $0.11 for sample utilities in Northern and Southern California. Average, minimum, and maximum price respectively, are $2.63, $1.07, and $6.45 for the sample utilities in the Northern California and $1.53, $0.60, and $3.66 for the sample utilities in the Southern California. Average, minimum, and maximum of S.D. for the sample utilities in the Northern California respectively are $0.27; $0.102; $0.53. Average, minimum, and maximum of S.D. for the sample utilities in the Southern California, respectively are $0.142; $0.0006; $0.620.

Figure 2: Estimated Price Elasticity of Water Demand by Region and by Season in California



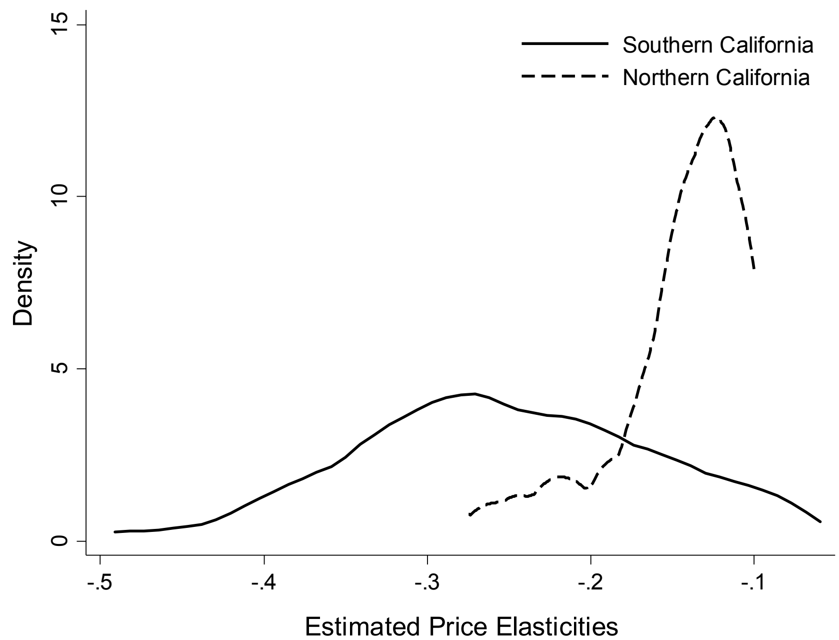
Note: Mean, S.D., minimum and maximum estimated price elasticity of demand for sample utilities in Southern California in the summer respectively are -0.33, 0.12, -0.61, and -0.1 and in the non-summer are -0.19, 0.09, -0.46, and -0.1. Mean, S.D., minimum and maximum estimated price elasticity of demand for sample utilities in Northern California in the summer and non-summer are similar and are -0.13, 0.05, -0.27, and -0.1.

Figure 3: Median *Prices per acre-foot by Utility in the Southern and Northern California*



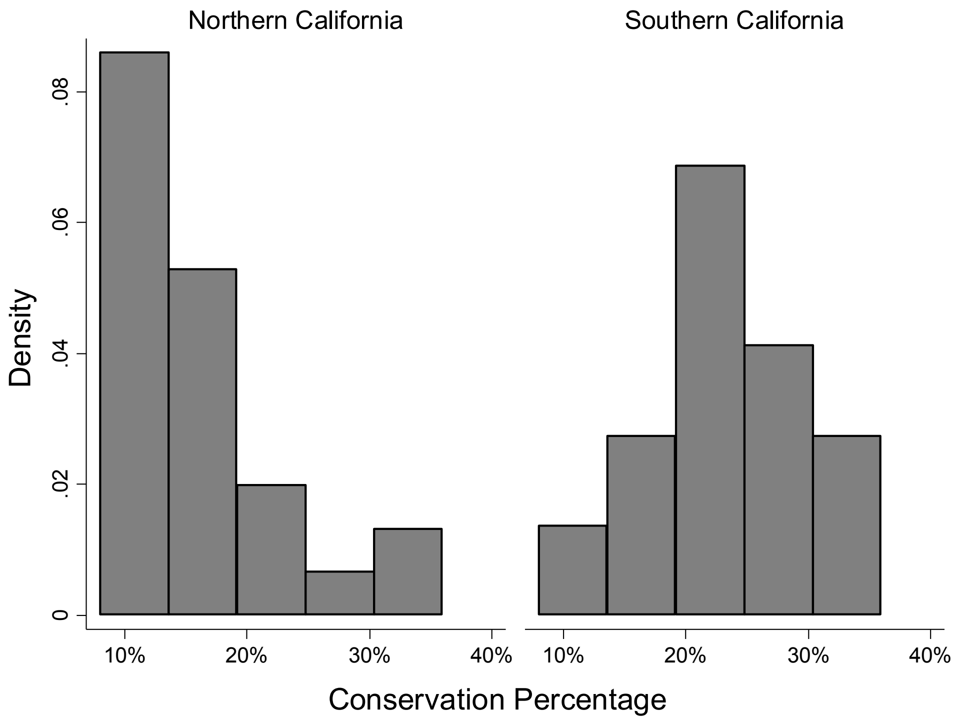
Note: 27 utilities are used from Northern California. Mean, minimum and maximum prices in Northern California utilities are $1,485, $709, and $2,755; 26 utilities are from Southern California. Mean, minimum and maximum prices in Southern California utilities are $1,157, $614, and $2,156.

Figure 4: *Estimated Price Elasticities in Urban Water Utilities by Region for Welfare Loss Analysis*



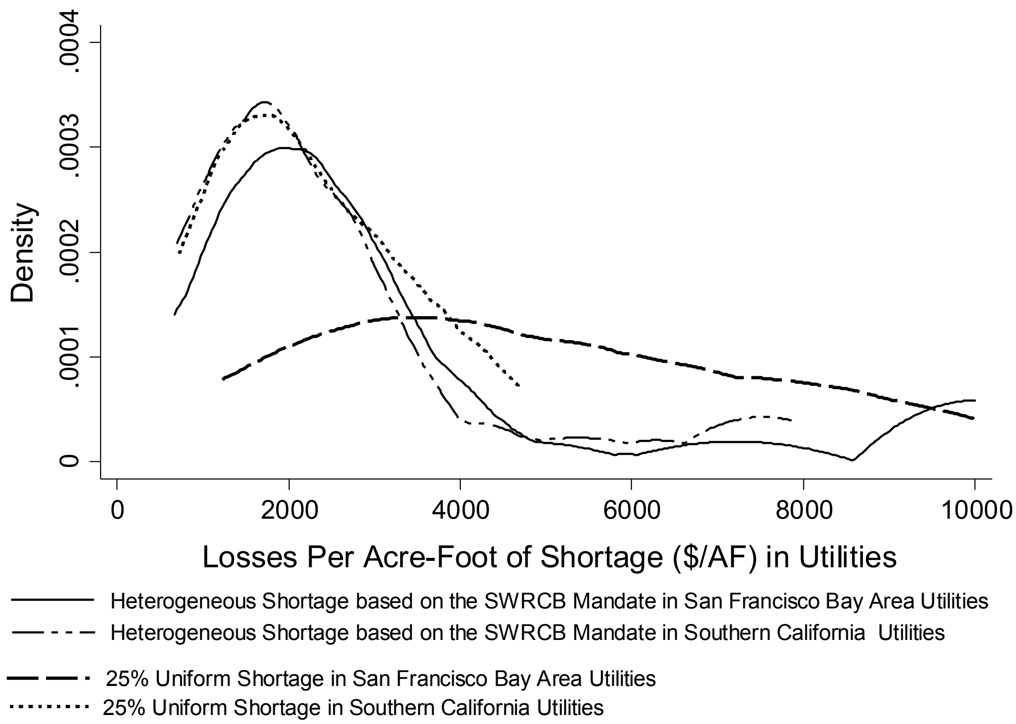
Note: Estimated price elasticities mean, minimum and maximum in Northern California utilities are -0.14, -0.27, and -0.1; estimated price elasticities mean, minimum and maximum in Southern California utilities are -0.25, -0.45, and -0.1. We truncated estimated elasticities at -0.1.

Figure 5: Distribution of Mandated Conservation across Utilities in Northern and Southern California.



Note: Utilities in the Northern California (27 utilities) on average required to cut back consumption by 15%. Minimum and maximum cutback for these utilities respectively, are 8%, and 36%. Utilities in the Southern California (26 utilities) on average were required to cut back consumption by 23%. Minimum and maximum cutbacks for these utilities respectively, are 8%, and 36%.

Figure 6: Heterogeneity in Welfare Losses for Northern California and Southern California.



Note: Per acre-foot welfare loss under 25% uniform shortage lies between $1,230 and $10,000 in San Francisco Bay Area. For southern California this number lies between $700 and $4,712. Under supply shortage based on the SWRCB mandate Northern California per acre-foot welfare loss lies between $665 and $10,000[5] with an average of $3,219 and in Southern California, this range is between $700 and $7,900 with an average of $1,829.

[5] Except one utility with $35,000 per acre foot loss.

Table 1: Urban Water Utilities Conservation Tiers and Count of the Utilities in each Tier

Tier	R-GPCD Range		# of Suppliers in Range	Conservation Standard
	From	To		
1			4	4%
2	0	64.99	27	8%
3	65	79.99	23	12%
4	80	94.99	42	16%
5	95	109.99	61	20%
6	110	129.99	45	24%
7	130	169.99	81	28%
8	170	214.99	61	32%
9	215	612.00	67	36%

Note: The mandate aim is to reduce the amount of water consumed statewide in urban areas by 25% from 2013 levels – roughly 1.3 million acre-foot of water. A total of 411 urban water utilities are required to reduce water supply (sum of column (4) in Table 1).

Table 2: Average Monthly Household Water Consumption in 2009 (Unit: CCF/Month)

Region	Variable	Mean	S.D.	Min.	Max.
All Sample Utilities	Average monthly	17.50	8.40	4.06	52.87
	Arid season	23.40	11.57	0.43	68.95
	Wet season	17.58	8.73	0.25	69.51
Sample Utilities in the Northern California	Average monthly	11.98	7.97	4.063	52.87
	Arid season	16.55	10.41	0.44	66.02
	Wet season	11.72	6.27	0.25	52.87
Sample Utilities in the Southern California	Average monthly	19.07	7.83	7.74	52.80
	Arid season	25.30	11.16	4.73	68.95
	Wet season	19.17	8.61	2.88	69.51

Notes: Average monthly household water consumption disruptions on a CCF basis lies between 5 to 15 CCF in Northern California and between 12 and 25 in Southern California.

Table 3: Residential Monthly Water Demand Estimation

	(1)	**(2)**	**(3)**	**(4)**
Ln(Price)	-0.43*** (0.015)	-0.17* (0.094)	-0.180* (0.102)	-0.190** (0.100)
Observations	5,573	5,573	5,525	5,525
Year Fixed Effects (Y=6)	*Yes*	*Yes*	*Yes*	*Yes*
Utility Fixed Effects (U=111)	*No*	*Yes*	*Yes*	*Yes*
County Specific t, t^2 (C=9)	*No*	*No*	*Yes*	*Yes*
Month Fixed Effects (M=12)	*No*	*No*	*No*	*Yes*
Weather Controls	*No*	*No*	*No*	*Yes*

Note: Huber-White standard errors reported in parentheses: *** p<0.01, ** p<0.05, and * p<0.1.

Table 4: Residential Monthly Water Demand Estimation (Additional Specifications)

	(5)	**(6)**	**(7)**	**(8)**
Ln(Price)	-1.96* (1.042)	-1.956* (1.043)	-1.463 (1.122)	-1.90* (1.043)
Ln(Price).Ln(Income)	0.433* (0.258)	0.433* (0.258)	0.371 (0.259)	0.426* (0.258)
Ln(Price).Summer		-0.031 (0.052)	-0.031 (0.052)	0.011 (0.061)
Ln(Price).MWD			-0.282 (0.284)	
Ln(Price).Summer.MWD				-0.154** (0.061)
Observations	5,477	5,477	5,477	5,477
Within R^2	0.55	0.55	0.55	0.55
Year Fixed Effects (Y=6)	*Yes*	*Yes*	*Yes*	*Yes*
Utility Fixed Effects (U=111)	*Yes*	*Yes*	*Yes*	*Yes*
County Specific t, t^2 (C=9)	*Yes*	*Yes*	*Yes*	*Yes*
Month Fixed Effects (M=12)	*Yes*	*Yes*	*Yes*	*Yes*
Weather Controls	*Yes*	*Yes*	*Yes*	*Yes*

Note: Huber-White standard errors reported in parentheses: *** p<0.01, ** p<0.05, and * p<0.1. Implied price elasticity using Column (1) specification indicates own price elasticity in an urban water utility with a median household income of $65,000 would be -0.15. $65,000 is the weighted median income by using an average number of households in each utility service area as a weight. Summary of implied price elasticities of the specifications after column (1) is presented in Table 5.

Table 5: Summary of Single Family Residential Price Elasticities

	Summer			
	No. Utilities	**Mean**	**Max**	**Min**
Southern California	90	-0.33	-0.1	-0.61
Northern California	21	-0.13	-0.1	-0.27
	Non-Summer			
Southern California	90	-0.19	-0.1	-0.46
Northern California	21	-0.13	-0.1	-0.27

Note: Minimum elasticities are truncated at -0.1.

Table 6: Per Acre-foot Welfare Loss Using 2009 as a Base Year

Assumptions by Scenario	**Welfare loss**
Scenario 1: - 25% cut uniformly - June- January	$3,796 [$2,859]
Scenario 2: - Heterogeneous supply shortage - June- January	$3,771 [$6,071]

Note: Standard deviation for mean welfare losses per acre-foot across 53 urban water utilities is reported in square brackets. We emphasize that the numbers reported in the square brackets are not standard errors; instead, they are the standard deviations associated with the calculation of mean welfare loss per acre-foot for the 53 urban water utilities.

Table 7: Welfare Losses Due to Shortages of 25% form Jun-September, and Cutback Based on the SWRCB Conservation Program in the Single Family Residential (SFR) Demand Sector

Panel A: San Francisco Bay Area Sample Utilities		
Quantity-weighted average price: $1,248/AF; Household-weighted avg. elasticity: -0.15. Total SFR demand (AF) from Jun-January: 132,952; Total SFR households: 454,799		
Supply shortage scenario	**25%**	**Conservation program**
Total loss ($ millions)	$147	$130
[95% Bootstrapped C.I.]	[$64-$171]	[$41-$131]
Average loss ($/AF)	$4,424	$6,132
[95% Bootstrapped C.I.]	[$1,937-$5,165]	[$1,952-$6,223]
Household WTP($/Month)	$40	$36
% increases in expenditures	87%	78%
Panel B: Southern California Sample Utilities		
Quantity-weighted average price: $1,231/AF; Household-weighted avg. elasticity: -0.26 Total SFR demand (AF) from Jun-January: 1,483,274; Total SFR households: 3,534,990		
Supply Shortage Scenario	**25%**	**Conservation program**
Total loss ($ millions)	$805	$713
[95% Bootstrapped C.I.]	[$560-$1,248]	[$490-$1,090]
Average loss ($/AF)	$2,171	$2,113
[95% Bootstrapped C.I.]	[$1,511-$3,366]	[$1,453-$3,230]
Household WTP($/month)	$28	$25
% increases in expenditures	43%	38%

Note: Square brackets report 95% confidence intervals for our estimates of total welfare losses and average welfare losses per acre-foot (AF) of supply disruption. Due to the fact that the elasticity estimates enter non-linearly into the welfare expression, these are bootstrapped confidence intervals with bootstrapping clustered at water utility level. The Household WTP measure divides the total loss reported in the first row by the total number of single family residential households in the region. The % increase in expenditures uses the welfare loss estimates to calculate how much households would be willing to increase their existing expenditures in percentage terms in order to avoid the percent disruption identified at the top of the corresponding column.