

Culpable Consumption: Residential Response to Price and Non-Price Water Conservation Measures

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Abstract

Growing urban water demand combined with a shifting global climate present urban water districts with an acute need for policy approaches that can induce both long- and short-run conservation behavior. Using quasi-experimental long-run variation in prices and exposure to short-run price and non-price policies during severe drought, I estimate the effectiveness of these policy approaches for urban water conservation. This paper is the first to not only identify the water conservation impact of public shame, but also isolate its effect from those due to moral suasion and price-based measures. By following the universe of single family water customers served by a major water district over time, I compare the impacts of different policies on the same households and avoid common sample selection issues. First, I utilize rich administrative panel data to characterize the evolution of causal price elasticities across multiple stages of drought. Next, I leverage quasi-experimental variation in exposure to fees, moral suasion, and public shame to separately identify consumer responses to each during the drought emergency. Demand models yield causal price elasticity estimates of -1 prior to adaptation that attenuate to -0.4 to -0.7 during and -0.2 to -0.5 post-drought, with high-usage households displaying the greatest responsiveness. While subject to behavioral interventions, top water users display no conservation response to excessive use fees. Moral suasion and public shaming show substantial short-run conservation impacts but display immense sensitivity to emergency messaging and consumer beliefs in crisis. Households called out by name in news stories display sizable reductions in water use even after prior exposure to moral suasion and fees, demonstrating the resilience of public shaming's conservation effect to crowding out by other concurrent policies. These findings yield important implications for the design of future urban water policies that can balance short and long-run conservation goals.

JEL: A13, D12, D91, H31, Q21, Q25, Q28, Q54

Keywords: urban water, public shame, moral suasion, price elasticities, drought policy

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1 Introduction

Climate change and rapid urbanization have established urban water security as a critical concern. Globally, more than 2 billion urban residents of developed and developing countries are projected to reside in water-scarce areas by 2050 (He et al. 2021). In the western United States, extensive reliance on outdoor irrigation places tremendous strain on urban water systems. Years of meager snowpack levels and extreme summer weather situate urban water districts in the difficult position of having to balance reduced long-run supply expectations with rising costs, higher summer demand, and increasingly frequent, severe drought.

In order to manage increased scarcity and growing demand, urban water districts around the globe require extensive knowledge of the policy approaches that can effectively induce water conservation over multiple time horizons. As climate change leads to chronically hotter and drier conditions, water districts must utilize policies that can shift residential consumers to lower long-run consumption paths and balance uncertain supplies (Buck et al. 2020). At the same time, climate change exacerbates short-run climate volatility, increasing both the frequency and severity of droughts (*IPCC 2021*). During these periods of temporary heightened scarcity, districts require policies that can quickly induce rapid, large-scale reductions in water use. By selecting policy approaches appropriate for inducing either long-term adaptive behavior or short-run consumption reduction, water districts can improve the stability and reliability of increasingly-volatile water supplies.

Although policymakers can choose from a wide set of available price and non-price instruments, which policy regimes are the most efficient for achieving water conservation goals remains an area of great debate. Price-based approaches come first to economists' minds for efficiency and cost-effectiveness reasons, but they may lose efficacy as households shift consumption to more essential indoor uses or may be constrained by government regulations. In recent years, interest has grown in the use of behavioral, non-price methods such as moral suasion and public shame. These information and social pressure-based policies show considerable promise to both reach agents unresponsive to price-based approaches (Johnson 2020) and affect change at dramatically lower cost in comparison to more traditional demand-side management strategies (Kahan and Posner 1999). While behavioral change due to moral suasion, peer comparison, and social pressure has been well-studied (Andreoni 1990; Allcott 2011; Dal Bó and Dal Bó 2014; Brent, Cook, and Olsen 2015; Nemati, Buck, and Soldati 2017), relatively little is known about

the potential role of public shame in inducing conservation behavior among high use individuals. This lack of knowledge is driven by the fact that very few existing policies implement public shaming, let alone introduce it quasi-randomly or concurrently with other policy instruments.

In this paper, I take advantage of unique quasi-experimental variation in contemporaneous exposure to price changes, moral suasion, and public shaming in San Francisco's East Bay Area to explore the relative effectiveness of price versus non-price approaches for short and long-run water conservation. I begin my analyses by estimating credibly causal price elasticities before, during, and after drought policies implemented in the face of historic scarcity. I first estimate long-run elasticities pre and post-drought using annual variation in marginal price schedules across space and time. I then leverage the implementation of an additional marginal price tier to identify elasticities for high usage households in response to short-run, policy-induced price changes.

Next, I identify the dynamic conservation effects of moral suasion and public shame separately from price changes during and after drought policies. During the height of the drought crisis, the water district implemented a bundled policy that resulted in quasi-random exposure to fees, moral appeals to conserve, and negative coverage by name in news stories after customers exceeded an arbitrary usage threshold. By nesting event studies for both behavioral instruments into the residential water demand model, I am able to estimate how treated households changed their consumption behavior following direct exposure to public shaming separately from moral suasion or financial penalties. Under parallel trends and treatment effect stationarity assumptions, I isolate the causal effects of each behavioral instrument for inducing conservation among top water users.

Administrative panel data for roughly 300,000 single family homes over eight years in San Francisco's East Bay Area provide rich variation in water use and prices over time. As the water district charges different marginal prices across three elevation boundaries, households in the same neighborhoods experience different nonlinear pricing schedules. The obscurity of the boundaries' locations minimizes concerns of sorting, and I confirm balance across boundaries through matching on observable characteristics. Differential price changes over time across consumption tiers and elevation bands contribute a further source of identifying variation. These considerable differences in prices for comparable homes across space and time allow use of an empirical strategy (Blundell, Duncan, and Meghir 1998; Saez, Slemrod, and Giertz 2012; Ito 2014) that isolates causal price responses from mean reversion and distributional shifts – sources

of bias that affect typical water price instruments.

Focusing on a water district spanning urban and suburban communities in varying micro-climates provides a study region with extensive heterogeneity in socioeconomic and weather conditions. Using data from 2012-2019, I am able to observe how households responded to both shifting long-run climate and short-run acute scarcity. Differences in outdoor irrigation needs for coastal and eastern residents with identical landscaping provides a plausibly exogenous source of variation in the probability of exceeding the usage threshold. Empirical models provide estimates of behavior in the context of extensive urban outdoor irrigation needs in the world's fifth largest economy.

Price response results yield evidence of large magnitude pre-emergency price elasticities that decrease in magnitude as the drought crisis grew more severe. Prior to the implementation of the district's main drought policies I estimate overall unitary price elasticities that are consistent with recent literature and are highly robust to the choice of price measure and sample. Once drought policies are implemented, these elasticities shrink in magnitude to -0.4 for all households and -0.7 for households that ever exceeded the usage threshold. I find no evidence of conservation responses to prices for households that violated the policy and were exposed to moral suasion or public shame, with large, positive price elasticities obtained for these top users while exposed to non-price measures during the policy period. Once the drought emergency ended, price elasticities fall further to -0.1 to -0.2 overall and -0.5 for high users. These findings reflect the many available margins of adjustment when outdoor water use is high and the stickiness of indoor water use following adoption of conservation practices.

Examining the conservation responses to moral suasion and public shame, I estimate large magnitude short-run responses that vanish once the drought emergency is lifted and consumer beliefs in the acute crisis fade. Moral suasion exposure results in a 10-15% reduction in water usage relative to control households for preferred specifications. Being publicly shamed prompts a 2-3 times larger conservation effect that is *in addition to* prior exposure to moral appeals and fees. These findings are highly robust across specifications in the presence of never-treated units and provide evidence of the resilience of public shaming's conservation effect to crowding out by other concurrent policies. Once the district ended its drought emergency roughly one year later, the conservation responses to both behavioral instruments quickly vanished, suggesting that the behavioral responses are not persistent long-term.

These results carry important implications for the future design of short and long-run water

conservation policies. The large-scale responses to moral suasion and public shame under short-run drought emergency provide strong evidence that these behavioral policy instruments can be effective tools for achieving discrete reductions during periods of acute shortage. In contrast, the calculated price increases necessary to match either non-price policy response are infeasibly large, matching prior evidence on small-magnitude responses to excessive use fees (Pratt, [in press](#)). The relative ineffectiveness of prices during temporary scarcity is unsurprising given the degree of observed adaptation behavior, with households already cutting non-essential water usage and shifting to less elastic regions of the demand curve prior to the implementation of drought emergencies. Further, the estimated positive price elasticities for households while exposed to behavioral instruments suggests that these non-price mechanisms dominated water users' focus during drought crisis.

In the long-run, prices remain effective at reaching high-usage households while moral suasion and public shame prove highly sensitive to messaging. Although average households display post-period price elasticities under one-fifth the size of those pre-drought emergency, top users remain relatively more elastic. The rapid disappearance of behavioral policy effects, once the signaling of crisis ends, mirrors prior evidence of habituation to moral suasion (Ferraro, Miranda, and Price [2011](#); Ito, Ida, and Tanaka [2018](#)) and suggests that conservation responses to behavioral instruments are unlikely to persist in the long-run when individuals no longer believe that such behavior is morally required to ensure availability for essential needs.

My findings contribute to three strands of literature. First, I contribute to the literature on causally-identified water price elasticities. While most prior studies are limited by a lack of quasi-experimental variation in prices, several recent studies have leveraged price variation due to seasonal variation in rates (Klaiber et al. [2014](#); Yoo et al. [2014](#)) or changes to the pricing structure itself (Nataraj and Hanemann [2011](#); Wichman [2014](#)). I extend on these works by utilizing an empirical strategy that isolates price responses from mean reversion and distributional shifts – sources of bias common in prior urban water demand studies. My study setting provides unprecedented degrees of price changes and follows the largest-yet set of single family homes through multiple stages of water scarcity and drought policy, allowing use of a rigorous control approach not possible in many settings.

Next, I contribute to two distinct literatures on residential responses to urban drought policies and on general responses to behavioral policies, respectively. While a limited set of prior studies in the first literature have examined settings that simultaneously employ price and non-price

drought policy instruments (Asci and Borisova 2014; Wichman, Taylor, and von Haefen 2016), this paper is the first to not only identify the water conservation impact of public shame, but also isolate its effect from those due to moral suasion and price-based measures. Prior evidence on behavioral responses to public shaming from the second literature are limited to firms' standards violations (Blackman, Afsah, and Ratunanda 2004; Schlenker and Scorse 2011; Johnson 2020) or income tax avoidance (Perez-Truglia and Troiano 2014; Dwenger and Treber 2018; Tsikas 2021); this paper presents the first evidence of individual responses in the context of natural resource conservation.

This paper proceeds as follows. Section 2 provides background on California's historic 2011-2017 drought and provides detail on the focus district's policies. Section 3 introduces the data sources and discusses water use trends over time. Section 4 develops the residential water demand model and discusses the identification strategies for obtaining price elasticities and behavioral responses to drought policies. Section 5 presents results, and Section 6 concludes.

2 Background

2.1 2011-2017 California Drought and Policy Landscape

From 2011 to 2017, California experienced historic water shortages. 2012-2014 marked the driest and hottest three-year period yet on record for the world's fifth-largest economy (Mann and Gleick 2015). Although Governor Jerry Brown proclaimed a state of drought emergency in January 2014, statewide snowpack water content stood at only 5% of typical levels by April 1, 2015 (California Department of Water Resources 2015). As a result of this depleted snowpack and reduced snow melt – a primary source of California's potable water supply – many urban water districts around the state soon faced critically low reservoir storage levels well below historic averages.

To combat impending water shortfalls, the state took unprecedented action in curtailing urban water demand. In April 2015, Governor Brown issued Executive Order B-29-15 which mandated a 25% statewide reduction in urban water deliveries relative to 2013 levels.¹ In addition, the order directed water districts "to develop rate structures and other pricing mechanisms,

1. While the state sought a 25% overall reduction in urban water deliveries, individual districts faced potentially smaller or larger mandated cuts. For example, while districts whose residents averaged under 65 gallons per capita-day in summer 2014 faced necessary reductions of only 8%, districts with average usage above 215 gallons per capita-day were subject to reduce deliveries by 36%.

including but not limited to surcharges, fees, and penalties, to maximize water conservation consistent with statewide water restrictions” (California Executive Order B-29-15 [2015](#)).

Water districts across the state now faced both an immediate need to develop conservation policies to bring about the necessary reductions and a newfound flexibility in the policy instruments available to bring about those reductions. Historically, water districts in California have been limited in their ability to set prices beyond levels that recover costs of provision (CA Proposition 218). While districts may include fixed charges or implement increasing block pricing schedules, their rate structures must be approved and ultimately set by the California Public Utilities Commission to ensure they are not operating as a natural monopoly. However, as a result of state drought emergencies and executive orders, water districts could now design price-base policies for the specific purpose of promoting conservation behavior. Further, districts were free to implement a broad set of non-price policies instead of or in combination with price-based measures.

As a result of this newfound policy freedom, water districts around the state adopted a diverse range of price and non-price based policies to meet state-mandated reductions. Table 1 summarises the policy instruments employed by a subset of urban water districts across California. Many water districts – including El Dorado, El Centro, Imperial, and Placer water districts – designed online or mail education campaigns that taught residential customers about ways to reduce indoor and outdoor water usage. Districts often implemented rebate programs, providing financial incentives for customers to adopt water-efficient outdoor irrigation technology (i.e. smart irrigation controllers or in-line drip systems), low-flow showerheads or toilets, or even replace lawns with drought-resistant landscaping. Common price-based policy instruments include the introduction of drought surcharges or replacing flat fee structures with increasing block pricing. In many cases, water districts employed a combination of listed policy instruments, launching mail or web-based information campaigns, introducing rebate programs for high-efficiency landscaping equipment, or modifying pricing structures to reduce demand overall or among top water users.

A common theme among water districts was the targeting of non-essential water use among high-usage customers. While the lion’s share of California households utilize moderate amounts of water every month, a disproportionate share of water is utilized by consumers in the top few percent of the water use distribution. As a result, many districts identified top users as the richest source of urban water conservation. The least-invasive policies included contacting

outlier users – either over the phone or by placing physical placards on their front doors. Several districts, including Apple Valley Ranchos, San Jose, and Santa Cruz, introduced excessive use fees that increased the marginal price of water for volumes used beyond a set threshold.

2.2 East Bay Municipal Utility District and the Excessive Use Penalty Ordinance

While several other California water districts targeted excessive users in various ways, the most unique policy solution was introduced by the East Bay Municipal Utility District (henceforth EBMUD). Located in San Francisco’s East Bay Area, EBMUD delivers over 150 million gallons daily to 1.4 million water customers in Alameda and Contra Costa counties. Figure 1 provides a map of the EBMUD service area and shows its location within California. The EBMUD service region spans 332 square miles, bounded to the west by the Richmond and Bay Bridges and to the north by the Benicia Bridge. The region extends as far south as San Lorenzo and covers communities along the Highway 24 and 680 corridors through to San Ramon.

EBMUD serves a highly socio-economically and climatically diverse customer base due to its extensive geographic coverage. EBMUD delivers nearly two-thirds of its water to residential customers from downtown urban Oakland to wealthy suburban communities high atop the Berkeley hills or on large lots nestled in the foothills of Mount Diablo to the east. As the district is bisected by a portion of the Pacific Coast mountain range known as the Berkeley hills, residents to the west experience cooler, moister conditions relative to customers in the eastern foothills. These factors lead to substantial heterogeneity in usage across communities: while the average residential EBMUD customer consumed 73 gallons per capita-day in 2014, residents of Oakland averaged a mere 57 gallons per capita-day while residents of the affluent Diablo suburb averaged 345 gallons.

As its primary means of meeting their state-mandated 20% delivery reductions, the district designed and adopted the Excessive Water Use Penalty Ordinance (henceforth EUP). While EBMUD implemented drought surcharges for all customers, the district identified “discretionary, nonessential use” by single-family homes as the greatest source of potential savings. On average, over 50% of annual residential deliveries in the district goes to irrigate lawns or other outdoor landscaping – uses not deemed essential for the common good by state legislation. Further, the distribution of historical water use in the district is top-heavy: from 2012 to 2019, 36% of residential water was used in the top 10% of bills.

To induce conservation behavior among top users, the EUP introduced a mix of three price and non-price policy instruments. First, the policy introduced a limit of 80 hundred cubic feet (80 CCF, or 59,840 gallons) of water per two-month billing cycle for all single-family residential water customers, regardless of location or past usage. Households that exceeded this limit faced a \$2 penalty in addition to the typical marginal price for each unit of water used above the threshold. This price mechanism functioned akin to an additional increasing block price tier, raising marginal prices by 36-45% for only the highest usage households. During the sample period, only 2% of bills exceeded the usage threshold. However, this small subset of bills represented a disproportionate share of total water deliveries, consuming 13.6% of total residential water.

This seemingly arbitrary threshold value was chosen for two main reasons. First, it represented a level well beyond that of a typical residential customer. On average, a single-family home in the EBMUD service area consumed approximately 250 gallons per day (Cuff and Rogers 2015).² The 80 CCF threshold meant that a household would need to consume over four times the average level in order to violate. Second, the threshold had a clear interpretation in terms of daily flow rates: a water volume of 80 units equals approximately 1,000 gallons per day for a standard billing cycle.

Second, the framing of penalties and violation messaging resulted in moral suasion exposure for all violating households. During the drought emergency, EBMUD sent letters to all high-usage households urging them to check for leaks and informing them that exceeding the threshold “is prohibited and has consequences.”³ District messaging referred to the fees as a “civil administrative penalty” for violating an ordinance needed to ensure “sufficient water for human consumption, sanitation, and fire protection.” Indeed, the EUP legislation itself made it unlawful for EBMUD customers to “willfully violate any provisions” of the policy. The moral violation messaging was also reflected on customers’ bills. Figure 2 provides a copy of an EBMUD bill for a household that violated the EUP and shows how the penalty amount was provided as a line item separate from typical usage volumes, elevation charges, and broad drought surcharges. This aspect of the policy mirrored broader messaging from the district that conveyed a moral

2. Note that substantial heterogeneity in water use exists between the district’s western cities and drier, affluent eastern suburbs. In 2014 residents in Berkeley and Oakland used 52 and 57 gallons per person per day, respectively, with household averages under 200 gallons per day. Residents of Alamo and Danville — two eastern towns with large homes and expansive lots — averaged 250 and 345 gallons per person per day respectively during the same period, with household averages approaching or exceeding the excessive use level of 1,000 gallons per day.

3. See Appendix Figure A.1 for a copy of the full letter.

need to eliminate nonessential irrigation and modify indoor water use behavior during drought.

Third, the EUP resulted in public shaming of a subset of top users who violated the policy. While no charges were ever pressed, violation of the EUP technically resulted in a misdemeanor offense for all customers who exceeded the usage threshold. Due to the particular language of California's Public Records Act, EBMUD was legally required to make available the names, addresses, and water usage of all violating customers if ever requested through a Public Records Act request. As a result, many regional and local newspapers and news stations placed records requests with the districts and obtained the identities of all violators. While EBMUD's warning letter to high-use households communicated the possibility of this information being released, it did not make the connection to the potential of news media coverage singling out individual water users.

Figure 3 works through the specific timing of the Excessive Use Penalty Ordinance. The EUP entered into effect for all residential bills beginning July 1, 2015 or later. On October 15, 2015, EBMUD created the first Excessive Use Report that contained information on all households that had exceeded the usage threshold by that time. Over the next eight months, EBMUD created eight additional reports, the last of which was created several weeks after the EUP ended and EBMUD lifted the district-wide drought emergency due to increased reservoir levels and a sufficiently wet winter. Soon after each of the reports was created, regional news outlets obtained the lists and began publishing news articles that called individual violators out by name. These articles and television news segments often referred to violators as water "hogs," "wasters," or "guzzlers" and frequently lambasted their excessive water use while mentioning their neighborhood of residence or address itself.

Publicly shamed violators largely fell into one of two camps. The first type of article focused on "locally relevant" violators: retired or current professional athletes, musicians, business executives, as well as prominent university faculty and even news anchors themselves. Newspapers published stories about these individuals not because their usage was particularly different from other violators, but because their names were known and could likely generate page views. The second type consisted of "high-shock" users: households who experienced a particularly large water shock relative to other violators in a given period. These households often had typical water use levels in line with other violators, but happened to have abnormally high use in one billing cycle that pushed them either to the top of a particular report or to the top for a given city. Figures 4a-4b provide examples of each type of article.

3 Data

To investigate the price responsiveness of EBMUD customers over time and top users' responses to moral suasion and public shame, I obtain administrative panel data directly from the water district. Water use data cover the universe of billing cycles for residential customers during the period of April 1, 2012 through May 31, 2019. Each observation includes the billing cycle start and end dates, water consumption, elevation band, and location information. Water usage is provided in hundred cubic feet units (CCF), which I convert to gallons per day (GPD) to account for slight differences in billing cycle lengths and to match messaging on consumer bills.⁴ The overwhelming majority of EBMUD customers are billed every two months, for a total of six billing cycles per year.⁵

I obtain pricing schedules for each fiscal year from the district website. All EBMUD customers pay a fixed charge common to residential meters (5/8 or 3/4 inch diameter) in each billing cycle. Residential customers also face increasing block-tier pricing for all units of water consumed across three usage tiers. Tier 1 marginal prices are charged for all units of water consumed between 0 and 14 (0-172 GPD), which is set to “the average indoor water year-round usage for single-family residential customers” and represents permanent demand across all seasons. Tier 2 (15-32 CCF/172-393 GPD) and tier 3 (over 32 CCF/393 GPD) marginal prices are set progressively higher to recoup greater portions of the costs associated with fulfilling water demand during peak periods. Each year, planned rate increases to fixed charges and marginal prices in each tier come into effect at the start of the district’s fiscal year on July 1 to account for changes in costs. Using this information I compute marginal and average prices for every billing cycle based on each customers’ consumed water volume. Throughout analyses, I deflate all prices relative to 2012 dollars using the Gross Domestic Product Implicit Price Deflator (U.S. Bureau of Economic Analysis [2021](#)).

As a result of variable price changes each year across the marginal price schedule, drought surcharges, and elevation fees, EBMUD’s price structure provides unprecedented variation over space and time. Figure 5 illustrates this variation, plotting the marginal prices over time of consuming a median volume of water (in marginal price tier 1) for households in each of the

4. 1 CCF, or unit, equals 748.052 gallons.

5. As meters are read manually, the number of days in a billing cycle will be slightly above or below an exact two month interval. Monthly billing occurs for a small percentage of cases that include “reasonable and justifiable customer requests” and customers for whom the average monthly bill exceeds \$1,500 (typically commercial customers), or in cases of past credit/collection issues.

three elevation bands. The differences in marginal prices across elevation bands reflect per-unit charges that recoup the costs of pumping water to homes in higher pressure zones (roughly 200-600 feet above sea level for band 2 and above 600 feet for band 3).⁶ While marginal prices within a given elevation band change each year, the relative growth between bands varies over time with the gap growing on average throughout the sample period. Further, at any given point in time, households consuming identical volumes face different marginal prices due solely to differences in pumping costs. Identical patterns hold for consumption in tiers 2 and 3, with marginal prices increasing by 83% and 97%, respectively, during the sample period. Further, the addition of per-unit drought surcharges during the height of drought conditions resulted in a period of large increases followed by decreases to both marginal and average prices.⁷ This variation provides an ideal setting in which to investigate price responsiveness of urban water users.

Cases of excessive water usage during the drought policy period are obtained under a public records request with EBMUD. These data consist of all instances of household water usage that exceeded the 1,000 gallon per day threshold while the Excessive Use Penalty was in effect. Each entry includes the name, address, city, water usage (in CCF and in gallons per day), statement date, and cycle start/end dates for each violation. These data are a corrected version of those previously obtained by regional news media, omitting instances revised due to leaks or other issues. After merging with the main water use sample, 6,403 violations by 4,951 households remain.

I obtain incidences of public shaming by news media using the NewsBank repository and direct searches of regional newspapers and TV stations. NewsBank indexes articles from 189 regional and statewide print and web-only news sources in California. I performed a targeted search for references to East Bay Municipal Utility District, EBMUD, excessive use, water guzzler, and water hog. Title and search term matches for the 744 returned articles were then manually inspected, noting down any by-name mention of Excessive Use Penalty violators. I perform an identical search procedure for several Bay Area newspapers not available through NewsBank (including the Daily Californian and the Alameda Sun) and all stories (print and video) from the local TV news stations NBC Bay Area, CBS KPIX, Fox KTVU 2, KRON 4,

6. See Section 4.1.1 for a more detailed discussion of a home's assignment into elevation bands and the resulting identifying price variation. Appendix Table A.1 also reports the exact elevation surcharge amounts in each fiscal year.

7. See Appendix Table A.2 for exact drought surcharge values. EBMUD enacted Stage 4 (critical) drought in fiscal year 2016. While proposed, surcharges for Stages 1-3 were never implemented.

and ABC 7. These two search procedures yield 51 articles with names that match directly to instances of EUP violation. In total, 61 households are called out by name across 202 unique violator/article combinations.

I use PRISM Climate Group’s AN81d gridded daily weather dataset to construct climatic variables (PRISM Climate Group). PRISM inputs weather station data into a climate model that allows realized weather to vary with elevation, coastal atmospheres, and terrain barriers – features that are all present in the San Francisco East Bay – and outputs temperature and precipitation in 4 kilometer square grid cells (PRISM Climate Group). Using these data, I construct household by billing cycle-level measures of experienced rainfall and precipitation that precisely match weather conditions that occurred during between a particular set of start and end dates. Covered grid cells are obtained by matching customers’ addresses to parcel shape files obtained from the Alameda and Contra Costa County Assessor property files. I further use the property files to limit the sample to only detached, single family homes.

Table 2 summarizes billing cycle characteristics and excessive use during the sample period for the 10,709,816 observations. The first columns report the means and standard deviations across variables for all 301,271 unique households in the sample. The next columns report summary statistics just for the 4,951 “Excessive Users” who violated the EUP by using over 1,000 gallons per day while the policy was in effect. During the sample period the average EBMUD household consumed 18 CCF of water in sixty days, or just over 225 gallons per day. However, the large standard deviation of 280 gallons per day signals considerable heterogeneity, due in part to the presence of high usage households.⁸ On average, customers face a marginal price of \$3.76, less than half that of the typical average price of \$7.59. Including service charges, the average customer paid a total water bill of \$104.67. The EBMUD service area is topographically varied; roughly 36% of billing cycles during the sample period stem from homes in elevation band 2 (approximately 200-600 feet above sea level) and an additional 9.5% from homes in band 3 (roughly more than 600ft). The average single family home in the sample sits on a lot roughly 0.15 acres in size and has a home over 1,800 square feet in size. The mean billing cycle experienced a total of 312 growing degree days accumulated beyond 10°C and received 95.7 millimeters of rain (with considerable variation throughout the year).

Focusing on households that violated the EUP shows the dramatic amounts of water con-

8. Although only 1.7% of observations used over 1,000 gallons per day (surpassing the Excessive Use Penalty Ordinance’s limit), the total cases of “Excessive” use exceed 200,000 instances. Over 9% of total observations come from households that ever exceed this limit.

sumed by these users. These households averaged just over 1,000 gallons per day during the sample period, with water use in 49% of their billing cycles exceeding the EUP usage threshold. Due to this high water use, their average water bill reached a staggering \$502 dollars. These customers are more frequently located at higher elevation bands, reflecting the concentration of affluent suburbs around the Berkeley hills or in the foothills of Mount Diablo. Home and lot sizes reflect the relatively high affluence of violating households, with EUP violations occurring on lots that average over half an acre in size with homes in excess of 3,800 square feet. Broad weather patterns experienced by high-usage households are not systematically different from those seen by all households, with top users also accumulating just over 300 growing degree days and 100 millimeters of precipitation per average billing cycle.

3.1 Trends in Water Use

Observing district-wide patterns in water use provides preliminary evidence of extensive district-wide conservation and responses to drought policies. Figure 6 plots the average water use measured in gallons per day for all single family homes in the EBMUD service area from April 2012 through May 2019. The dotted line reports the average usage for customers that violated the EUP and were exposed to fees, moral suasion, and potentially public shame (“EUs”). The solid line reports mean water use for all other detached single family home EBMUD customers that were not directly exposed to EUP policy instruments (“Control Households”).⁹

Three main patterns arise from the data. First, consumption by top users is both much higher across the sample period and more variable across seasons. While high-usage households consumed roughly double the average of all other residential customers during winter months, their summer consumption is often 4-5 times larger. A typical single family home consumed 200 – 315 gallons on average per day during observed summers, whereas households that ultimately violated the EUP averaged from 1220 to over 1800 gallons per day. Second, both groups of customers exhibit conservation trends prior to the height of the drought crisis. Both annual average and peak summer usage declined for each group from 2012 to 2014, providing initial evidence that households undertook adaptive behavior in response to local and state messaging prior to the implementation of policies during the height of drought crisis. Third, usage further declines for both groups while the EUP was in effect (indicated by the orange band). Peak consumption during summer 2015 greatly attenuated compared to prior years for both groups,

9. See Appendix Figure A.2 for trends in average and marginal prices during the sample period.

with winter consumption lower than 2012-2014 as well. These trends provide preliminary evidence that even while households adapted to changing water supplies in the early drought years, district-wide policies may have induced further conservation.

4 Empirical Framework

I next develop an empirical model of residential water demand to investigate how price elasticities evolved under these usage trends and to measure responses to price and non-price policy instruments employed by the EUP. Identification of causal price elasticities in this framework relies on two unique aspects of EBMUD’s water pricing schedules. First, there is cross-sectional variation in marginal prices that is independent of both historical and contemporaneous household water usage. Second, the proportional changes in marginal prices year-to-year differ between groups, providing differences in relative prices faced by each group over time.

4.1 Residential Water Demand Model

To obtain estimates of the long-run price elasticity for residential water, I employ differenced models of the form

$$\Delta \ln(Q_{it}) = \beta \Delta \ln(AP_{i,t-1}) + f(Q_{it-3}) + g(W_{it}) + \delta_{zt} + \epsilon_{it} \quad (1)$$

where $\ln(Q_{it})$ is the natural log of the gallons of water consumed per day by household i during billing cycle t , $\ln(AP_{i,t-1})$ is the natural log of average prices paid in the previous cycle (two months ago), $f(Q_{it-3})$ is a function of consumption three billing cycles (six months) prior, $g(W_{it})$ is a function of experienced weather, and δ_{zt} are zip code by billing cycle fixed effects.¹⁰ Rather than a one-period difference, I employ a year-long difference: $\Delta \ln(Q_{it}) = \ln(Q_{it}) - \ln(Q_{it-6})$. In this way the idiosyncratic error term $\epsilon_{it} = \mu_{it} - \mu_{it-6}$ can be thought of as the difference in demand shocks between the current period and the same billing cycle in the previous year.

Considerable attention has been paid of late to *which* price customers respond to; recently consumers have been found to primarily respond to average price, both in terms of household energy consumption (Ito 2014) and residential water behavior (Wichman 2014; Wichman, Tay-

10. While EBMUD technically bills in terms of water volume measured in hundred cubic feet, the price schedules posted online are communicated in flow rates and the “consumption information” section of the monthly bill is provided in terms of gallons used per day. Given that billing cycles can vary in length by several days, my preferred specifications utilize water flow rates in the dependent variable. Results of preferred specifications are robust to the use of water volume in hundred cubic feet.

lor, and von Haefen 2016). While I utilize average prices for my preferred specifications in Table 3 and later analyses, I also report results utilizing marginal prices that are statistically indistinguishable.¹¹

I employ a simulated instrument approach that targets concerns of both simultaneity and mean reversion (Ito 2014). Typical residential water price instruments seek to characterize the entire price schedule and include service charges in addition to marginal prices at as wide a range of consumption levels as possible (Olmstead 2009; Wichman, Taylor, and von Haefen 2016). While this approach targets the endogeneity of prices, it does not address the possibility of mean reversion – a substantial concern that is further heightened when analyzing policies that target high water usage. I specify the simulated instrument as

$$\widehat{\Delta \ln(AP)}_{it} = \ln(AP_t(Q_{it-3})) - \ln(AP_{t-6}(Q_{it-3})) \quad (2)$$

where the simulated change in log average price $\widehat{\Delta \ln(AP)}_{it}$ is calculated as the difference of two functions of past consumption. The first term, $\ln(AP_t(Q_{it-3}))$, is the log of current average price for a usage level equal to the household's consumption three billing cycles ago (i.e. a half year prior). The second term, $\ln(AP_{t-6}(Q_{it-3}))$, is the log of average prices when consuming the same quantity but given the price schedule from the same billing period in the previous year. Use of the household's consumption level six months prior ensures that identification of the simulated instrument stems from typical patterns in household consumption rather than instances of mean reversion (Blomquist and Selin 2010; Saez, Slemrod, and Giertz 2012) and does not introduce the correlation in water demand shocks that occurs when consumption in a fixed base period is used (Ito 2014).

Lagged consumption controls $f(Q_{it-3})$ account for structural shifts in the water demand distribution. A classic example of this issue arises from the domestic income tax schedule: households at the top 1% of the income distribution are likely to have experienced faster income growth than the rest of families in the top 10% (Saez, Slemrod, and Giertz 2012). In the residential water context, outdoor irrigation needs under climate change likely grow at a faster rate for the highest-usage households with more water-intensive landscaping relative to other high users with less irrigated land. Shifts in the underlying residential water use distribution

11. When both marginal and average prices are included in the same regression, individual elasticity estimates become more volatile. However, the sum of both elasticities is nearly identical to results presented in Table 3 for each price measure on its own – reflecting the lack of cross-sectional variation in service charges to distinguish one price measure from the other.

over time will likely lead to divergent trends between households at different levels of water use, resulting in correlation between the residual ϵ_{it} and past consumption – and ultimately residual correlation with past prices. By including a flexible set of past consumption controls I am able to eliminate this residual correlation channel.

Importantly, this control structure also serves to minimize bias resulting from mean reversion. Households that experience a particularly large water shock in the current period are mechanically much more likely to decrease their water usage in the next period than a comparable household with a smaller shock. Failure to control for a household’s relative position in the water use distribution will then result in price elasticity estimates that conflate actual price responses with differential patterns of mean reversion.

To minimize the amount of imposed structure, my preferred models specify $f(Q_{it-3})$ as a vector of usage percentile-by-time fixed effects (Ito 2014). For each billing cycle, I calculate the usage percentile into which each household’s consumption six months prior (Q_{it-3}) fell. These percentiles are then interacted with each month-year, yielding a dummy variable for each usage percentile in every sample month.¹² As EBMUD customers on either side of elevation band boundaries face different marginal prices at all consumption tiers in any given period, I am able to include such a flexible set of past consumption controls without absorbing all identifying price variation. In Table 3 I also report results from models that specify $f(Q_{it-3})$ as a cubic spline with knots at each decile of lagged consumption (as with the weather controls).

To control for differences in weather both over time and across space, I include the set of temperature and precipitation controls $g(W_{it})$. As the sample period includes both wet winters and historical drought periods, substantial variation exists in the temperatures and amount of precipitation experienced by a given household year-to-year. Geographic differences in climate and elevation contribute to additional, cross-sectional variation in weather. My preferred specifications use semi-parametric controls for both temperature and precipitation and include cubic splines of both mean growing degree days and total precipitation with knots included at each decile of the variables’ distribution.

The set of fixed effects δ_{zt} account for remaining unobserved spatial and temporal water demand shifters. In my preferred specifications I model δ_{zt} as the interaction of month-year and nine-digit zipcode (e.g. July 2015 times 94597-0001).¹³ In so doing I control for unobservable

12. This process results in a set of 3,800 dummy variables for the pre-drought policy period and 8,600 for analyses utilizing the entire sample.

13. As the sample includes observations across 54,591 unique nine-digit zipcode, this control approach adds an

determinants of changes to annual water demand that vary by month but are common to homes within the narrow area delineated by zipcode routes. I also report results that alternately specify δ_{zt} using different combinations of month of year and 5-digit zip codes. Time-invariant household characteristics are removed through differencing.

4.1.1 Quasi-Experimental Price Variation

The nature of the EBMUD service area and the district's pricing schedule provide a useful source of identifying variation for estimating water demand. First, while sorting around a geographic discontinuity is a first-order concern in cross-sectional analyses, it is less of a concern in the present panel context. Second, residents do not have a choice of water provider; once a resident locates within the EBMUD service area they must use the district as their water provider. While residents could theoretically relocate to lower elevation bands within the EBMUD service area to reduce or altogether avoid elevation surcharges, any such re-sorting is complicated by the opacity of the elevation band assignment process along with the financial and hassle costs of moving.

EBMUD elevation surcharges are determined based on the pressure zone in which a home is located. The EBMUD service area is divided into 130 pressure zones that are categorized based on "elements that include elevation and pressure." Pressure zones are combined into three elevation bands, each with their own elevation surcharges designed to recoup costs associated with pumping. Table A.3 summarizes the determinants of elevation band membership and each band's surcharge. No surcharge exists for homes in elevation band 1, which consists of pressure zones that do not require any pumping for water delivery (the case for most homes within 200 feet of sea level). Homes in elevation band 2 are in pressure zones that require some pumping, and are typically at elevations of 200-600 feet above sea level. Homes in elevation band 2 face marginal prices that are between 12 and 20% higher than homes in elevation band 1, with the exact surcharge varying both over time and across usage tiers. Elevation band 3 consists of homes in pressure bands that require "considerable" pumping, which is needed for most homes above 600 feet above sea level. Homes in band 3 pay between 23 and 42% more per unit of water than homes that do not require pumping.¹⁴

Figure 7 shows the arbitrary nature of the district's elevation thresholds. This neighborhood

additional vector of 646,124 fixed effects that absorbs nearly all variation in experienced weather.

14. See Appendix Table A.3 for a summary of elevation band surcharges and the percent of sampled homes that fall within each band.

in Pinole provides a typical example of how elevation thresholds meander through neighborhoods, with homes in elevation band 1 (orange) often directly next door to or across the street from others in elevation band 2 (pink). In many cases homes that share the same block or even the same elevation face different elevation surcharges, creating substantial variation in the marginal price of water for comparable homes along the band thresholds. For neighborhoods like these around the boundaries, prospective residents would need to both view a home's past water bill and have prior knowledge of the elevation surcharge system to understand how marginal prices may differ between seemingly-identical homes in the neighborhood. Appendix Table A.4 confirms the similarity of homes near to either side of the elevation thresholds in Alameda County, strengthening the assumption that there are likely no structural differences in observable or unobservable characteristics that impact water demand across the elevation boundaries.

The structure of excessive use fees further allows for isolating responses of top users to short-run, policy-induced price changes. Beginning in July 2015, the EUP added excessive use penalties that functioned as a new, fourth marginal price tier for top users. A high-usage household with a constant consumption level between June and August now faced drastically different costs of consuming a marginal unit of water across adjacent bills. Similarly, the policy introduced a sizable gap in marginal price between a home consuming 1,005 gallons per day and one consuming just below the threshold. As a result, this temporary marginal price tier provides a source of identifying variation for distinguishing excessive users' short-run responses to temporary fees from annual changes to the usual marginal price schedule.

4.2 Behavioral Responses to Non-Price Policy Instruments

To identify the effects of moral suasion and public shame resulting from the Excessive Use Penalty, I extend Eq. 1 to allow price responses to vary prior to, during, and after the EUP and include relevant non-price policy elements to capture response dynamics:

$$\begin{aligned} \Delta \ln(Q_{it}) = & \beta_1 \Delta \widehat{\ln(AP)}_{it} + \beta_2 (\text{EUP} \times \Delta \widehat{\ln(AP)}_{it}) + \beta_3 (\text{Post-EUP} \times \Delta \widehat{\ln(AP)}_{it}) \\ & + \sum_{k=-18}^{18} (\theta^k \text{Suasion}_{it}^k + \tau^k \text{Shamed}_{it}^k) + f(Q_{it-3}) + g(W_{it}) + \delta_{zt} + \epsilon_{it}. \end{aligned} \quad (3)$$

The term $\text{EUP} \times \Delta \widehat{\ln(AP)}_{it-1}$ interacts the simulated average price instrument with a dummy variable equal to one for billing cycles that occurred while the EUP was in effect (July

1, 2015 to May 3, 2016) while the term Post-EUP $\times \widehat{\Delta \ln(AP)}_{it-1}$ allows the average price response to differ after the district's drought emergency ended. As Figure 6 illustrated, EBMUD customers substantially reduced their water use prior to the EUP's start. If households had already adopted conservation behavior and reduced their propensity to conserve, then they would likely appear less responsive to drought surcharges and penalties during the drought policy period which would lead to a positive β_2 . Adoption of medium to long-run conservation practices would similarly suggest $\beta_3 > 0$.

I specify concurrent responses to both moral suasion and public shaming using event studies. Each element $Suasion_{it}^k$ is a dummy variable, equal to one for a household k billing cycles since first violating the Excessive Use Penalty, and zero otherwise. $k = 0$ for the billing cycle when a household first violates the policy by using over 1,000 gallons per day and $k = 6$ for billing cycles one year later. As a result, each element of the post-treatment coefficient vector $\{\theta^1, \theta^2, \dots, \theta^{18}\}$ captures any differential annual change in water use and measures the isolated response to the district's moral conservation appeals two months to three years after first exposure, while controlling for simultaneous fees and public shaming. If violating households responded to the noncompliance language present on their bills, we would expect $\theta^k < 0$ while values close to zero suggest average non-responsiveness.

Similarly, the vector of dummy variables $Shamed_{it}^k$ models household responses to public shaming separate from price or moral suasion effects. For households called out by name in at least one related news article or video, I set the $Shamed_{it}^0$ equal to one during the billing cycle when a household is first mentioned by name.¹⁵ Importantly, shaming coefficients estimate responses *in addition to* prior moral suasion exposure: account holders' names were only published once they had violated the Excessive Use Penalty and after receiving a bill with moral suasion messaging.¹⁶ To the extent that residential water users experience disutility from negative news coverage, we would expect a reduction in water use and $\tau^k < 0$ for all post-exposure periods where $k \geq 0$. To ensure that dynamic treatment effects are identified separately from time trends, I bin both endpoints by setting $X_{it}^{-18} = 1 \forall k \leq -18$ and $X_{it}^{18} = 1 \forall k \geq 18$ for $X \in \{Shamed, Suasion\}$ (Schmidheiny and Siegloch 2019). Following convention, I drop the $k = -1$ bin and normalize all event-time effects relative to the billing cycles before being publicly shamed and before first Excessive Use Policy violation. To account for potential differ-

15. Findings are robust to specification of the $k = 0$ period as the first full billing cycle after public shaming.

16. On average, first shaming occurs 39.9 days after committing one's first EUP violation.

ences in pre-treatment conservation behavior among eventually treated households, I residualize $\Delta \ln(Q_{it})$ of treatment cohort-specific pre-trends (Goodman-Bacon, [in press](#)).

4.2.1 Identification of Responses to Behavioral Drought Policy Measures

Interpretation of $\hat{\theta}^k$, $\hat{\tau}^k$ as unbiased estimates of the causal impacts of moral suasion and public shaming on residential water use rely on two key assumptions. First, unbiasedness relies on a parallel trends assumption: the trends in water use over time among the non-violating households (for moral suasion) and the violating but unshamed households (for public shaming) are what the trends would have been for the violating/shamed households absent the treatment(s). Second, an assumption of stationarity for the average treatment effect on the treated in each treatment cohort (households first treated in the same period) ensures recovery of causally interpretable event-time estimates (Sun and Abraham, [in press](#)). That is, after conditioning on the time since treatment and included controls, cohort-level ATTs do not systematically differ from one another. As preferred specifications of Eq. 3 account for time-invariant household characteristics, experienced weather, and include Zip-9 by month-year and percentile of past consumption by month-year fixed effects, potential violations of this assumption requires remaining changes in unobservable demand determinants or water shocks over time to be associated with different treatment effect paths.

$Suasion_{it}^k$ and $Shamed_{it}^k$ coefficients reflect intent to treat estimators. Despite observing which households received bills containing a moral suasion message or were featured in a local news story, I cannot guarantee whether the household was actually exposed to each behavioral policy component. Households with paperless billing enabled could use the district's web portal to pay their water bill without ever directly viewing the bill and fail to see the moral suasion appeal. Use of auto-pay further reduces a customer's likelihood of observing the bill's conservation messaging. Even if a homes' bills were handled manually they may not have been seen by the property's residents. Compared to their lower-usage neighbors, high-usage households on large lots are more likely to employ landscape services that are responsible for managing water bills. Although media coverage of the policy was widespread and many shamed households were called out across multiple news sites or directly contacted by reporters, a household would miss the story altogether if they relied on national news providers and a friend or neighbor failed to alert them. In this way both sets of treatment effects likely represent lower bounds on the overall impact of the behavioral drought interventions.

5 Results

I next report results showing how price elasticities evolved over the sample period in response to changing water scarcity and to what extent high-usage households responded to price and non-price EUP policy instruments.

5.1 Pre-Drought Price Elasticities

Table 3 reports results for average and marginal price models from estimating Equation 1. These models use data covering the period April 1, 2012 through July 28, 2015, prior to the implementation of the Excessive Use Penalty. The top panel reports estimates using average price measures while the bottom panel reports comparable estimates where marginal price variables are specified instead. Column (1) provides estimates from an ordinary least squares regression in differences with month-year by Zip-9 fixed effects but without the simulated average price instrument or weather controls. Column (2) adds cubic splines for precipitation and growing degree days in each billing cycle. Column (3) adds the simulated price instrument but omits past consumption controls $f(Q_{it-3})$. Columns (4) and (5) add past consumption controls $f(Q_{it-3})$, with Column (4) specifying cubic splines of six months-lagged consumption with notches at each decile and Column (5) using month-year by percentile of past consumption fixed effects. Column (6) adds to the specification of Column (5) an interaction of the price instrument with an indicator for households that ever used a level of water that would have been considered “excessive” under the Excessive Use Policy (over 1,000 gallons per day). All columns include month-year by 9-digit zip code fixed effects and standard errors are two-way clustered by 5-digit zip code and fiscal year to account for likely correlation patterns in water shocks (Colin and Miller 2015).

Turning first to the ordinary least squares specifications for average price in Columns (1) and (2) of the top panel, the models estimate price coefficients between -1.62 and -1.66. Once the price change variable is replaced with the simulated instrument, the coefficient estimate falls in magnitude to a nearly unit elastic value of -1.11 in Column (3). This elasticity estimate remains stable in Columns (4) and (5) when either control approach for past consumption is included, with point estimates between the cubic spline and distribution by time fixed effect approaches indistinguishable from one another. Allowing the price elasticity in Column (6) to vary for households who ever used over 1,000 gallons per day yields a negative but statistically

insignificant coefficient. This finding suggests that households who had at least one high water use draw in the pre-drought policy period did not respond to price changes in a way that was statistically distinguishable from lower usage households prior to implementation of drought measures.

Price elasticity estimates are unchanged when identified using variation in marginal prices. Despite recent empirical and theoretical findings that average price is likely the more salient measure for both residential water and energy decision-making purposes (Ito 2014; Wichman 2014; Wichman, Taylor, and von Haefen 2016), neoclassical theory remains unchanged in its prediction that utility-maximizing consumers should base water use decisions on marginal prices. Columns (1) and (2) in the bottom panel of Table 3 yield large, positive, and highly statistically significant coefficients that imply a more than 2 and a half percent *increase* in water use for each percent increase in price. Once the marginal price change is replaced with the corresponding instrument in Column (3), the coefficient falls to -1.02 and both remains stable as past consumption controls are added in Columns (4) and (5) and proves statistically indistinguishable from all corresponding average price elasticities. Once again we observe a negative but statistically insignificant coefficient on the interaction term in Column (6), yielding no additional evidence of systematic differences in price responsiveness across the arbitrary 1,000 gallons per day threshold. These estimates' equivalency to the average price coefficients is unsurprising given the lack of cross-sectional variation in service charges and identifying variation in both variables being driven by the marginal price differences across elevation bands.

The large magnitude of these price coefficients reflects the many, varied margins of adjustment available to households over time. During periods of temporary scarcity, residential water users may choose to make more temporary, intensive-margin adjustments in response to price changes that they expect to be short-lived. As price changes become more frequent and consumer expectations around the time path of water availability adjust, water users can make a wide range of decisions to more permanently shift their water needs. Replacement of old, inefficient toilets with current low-flow versions can save roughly 13,000 gallons per year while installation of efficient showerheads and clothes washers save approximately 8 gallons per day and 30 gallons per load, respectively (EPA 2021; Flamer 2021). Households looking to reduce outdoor irrigation use are often encouraged by water districts – at times with rebate incentives – to install drip irrigation systems or self-adjusting irrigation controllers and replace lawns with drought-resistant landscaping (EBMUD 2021; (BAWSCA) 2021; SoCal WaterSmart 2021; City

of Sacramento 2021; Valley Water 2021). In the long-run homeowners with in-ground pools could empty them or take the more drastic step of removing them altogether.

Elasticity estimates from preferred specifications are in line with recent causal estimates from the residential water demand literature. Nataraj and Hanemann (2011) use a regression discontinuity design around the introduction of an additional block tier for the marginal price schedule in Santa Cruz County, California. This block affected only high-usage households who consumed 40 or more CCF per two-month cycle and was implemented shortly after the easing of price and non-price controls during the state's 1987-1992 drought (Nataraj and Hanemann 2011). Although the authors interpret their findings as a -0.12 short-run marginal price elasticity, Wichman (2014) shows that the change in average price implied by their treatment effects corresponds to an average price elasticity of -1.16 (Wichman 2014).

Klaiber et al. (2014) utilize changes in the distribution of water consumption at the census block group level over a three year period in Phoenix, Arizona to estimate the price responses resulting from seasonal changes in marginal prices. They estimate a wide range of seasonal elasticities by water usage percentiles and obtain estimates from an annually-differenced model ranging between -1.93 and -1.53 for winter usage and -0.99 to -0.45 during summer months for 2000-2003 (Klaiber et al. 2014). This approach relies on interpretation of the intercept as a local approximation to the full price response and is potentially biased if the intercept term is not stable to alternate control specifications (Yoo et al. 2014). Yoo et al. (2014) employ a similar differenced regression that includes marginal price and obtain a long-run estimate of -1.16 over the period of 2000-2008. While bias arising from instability of the intercept is eliminated (Yoo et al. 2014), the city's pricing schedule does not exhibit cross-sectional variation in marginal prices, preventing the authors from including controls for past consumption as utilized here that can account for shifts in the underlying water use distribution over time.

5.1.1 Pre-Drought Policy Heterogeneity

Table 4 and Figure 8 explore variation in price responsiveness across measures of billing cycle weather conditions and typical water usage. These models account for the fact that residential consumers' sensitivity to price changes may look quite different during hot summer months or for high-usage households in comparison to colder winter periods or in more temperate climates.

Table 4 reports results from models estimated using Eq. 1 for specific seasonal and geographic sub-samples. Columns (1)-(4) estimate price elasticities and differentials for excessive users in

spring, summer, fall, and winter billing cycles respectively. While point estimates for the price instrument coefficient in spring, summer, and winter are highly similar to the overall estimates, the point estimate for fall is positive but statistically insignificant. Of these, only the summer price coefficient is statistically significant, suggesting greater uniformity in price responsiveness when outdoor irrigation needs are at their highest (as reflected by an average usage of 334 gallons per day). Once again no statistically identifiable difference in responsiveness is observed for households who ever use over 1,000 gallons per day during a billing cycle.

Columns (5) and (6) split the sample for 5-digit zipcodes to the east and west of the Berkeley hills. A sub-range of the Pacific Coast Ranges, the Berkeley hills run north-south through the entire EBMUD service area, separating cities along the San Francisco Bay from their inland counterparts. As the range reaches nearly 2,000 feet in elevation, it blocks coastal fog from reaching the eastern cities – leading to drastically different climates and outdoor irrigation needs for comparable homes on either side.¹⁷ Coefficient estimates and mean water usage by region reflect these climatic differences. Homes west of the Berkeley hills use on average 187 gallons per day during the sample period, while homes to the east use over 120% more per day, at 412 gallons. The eastern region yields a -1.45 price coefficient in Column (6) while a much smaller magnitude effect of -0.83 is observed for homes in the western portion (statistically different from each other at the 95% level, $z = 2.06$). Residents to the east being over 75% more responsive to price than their western counterparts likely reflects their greater irrigation needs, higher average consumption levels, and subsequent larger propensity to conserve.

Figure 8 explores heterogeneity in price responsiveness across the distribution of weather exposure. Figure 8 plots the coefficients and 95% confidence intervals for the overall price elasticity at each percentile of experienced weather, with estimates for growing degree days reported in the top panel and for total precipitation in the bottom panel.¹⁸ The coefficient at 1% (far left) in the top panel indicates the estimated price elasticity for a home that experienced the first percentile of growing degree days during their billing cycle (no days with average daily temperature above 10°C) with the furthest right estimate reporting the same for the 99th percentile (664 accumulated growing degree days). The bottom panel of Figure 8 reports

17. These differences in outdoor irrigation needs are reflected in water budget tables provided by the district. Homes east of the hills are expected to require an additional gallon per day for each hundred square feet of either lawn or shrubs (EBMUD 2021).

18. Estimates are obtained using models that follow Eq. 1 where the price instrument is interacted with each percentile of a given variable's distribution. Each point estimate is calculated as the sum of the percentile's interaction term and the coefficient on the baseline term (50th specified as the omitted group) with the standard error of the sum calculated from the relevant components of the variance-covariance matrix.

corresponding estimates for the distribution of rainfall (from 0mm at the 1st percentile through 354mm in the 99th).

Figure 8 shows the role that weather plays in informing water needs and sensitivity to price. In the top panel, billing cycles under the hottest conditions yield the largest magnitude coefficients, with an estimate of -1.7 for temperatures in the 99th percentile (664+ accumulated growing degree days). At the opposite ends of the spectrum we observe dramatically smaller effects. For households experiencing no or few accumulated growing degree days at the bottom of the temperature distribution, we observe greatly attenuated price elasticity estimates between -0.4 and -0.8. Estimates for the 2nd-8th and 9th-17th percentiles (all larger than -1) are statistically distinguishable from that of the 99th percentile. While point estimates decrease monotonically from the 1st through 99th percentiles, none are statistically different than at the median of the distribution (-1.1).

A similar but more extreme pattern holds across the distribution of rainfall in the bottom panel. Under no rainfall (1st-7th percentiles of billing cycles), households display a price elasticity of roughly -2.6, statistically distinguishable from the elasticity at the median (-1.1) and all but 13 percentiles in the bottom half of the distribution. Coefficients between the 2nd and 65th percentiles remain highly stable, and while point estimates increase nearly monotonically from the 75th through 95th percentiles they are statistically indistinguishable from one another. At the highest levels of rainfall (291mm for the 95th percentile) where households likely have no need for additional irrigation, estimated elasticities approach one and even become largely positive, with 96th-99th statistically different from the median estimate with estimates between -0.1 and 1.4.

Taken together, the panels in Figure 8 illustrate that homes exhibit their greatest price responsiveness under climatic conditions that prompt the greatest irrigation need. When temperature is highest and precipitation lowest – times when demand for outdoor irrigation water and total bills would be at their peaks – we observe that households are the most responsive to changes in price. As temperature falls and precipitation increases, irrigation needs decline, a household's overall expenditures on residential water fall – and so too does their sensitivity to price. These patterns suggest that price sensitivity falls as a household's water usage reduces to expected indoor-only consumption levels and that many households are willing to substitute away from outdoor irrigation in cases of both high climatic need and high prices.

To explore the role of chronic usage on price responsiveness, Appendix Figure A.3 estimates

price elasticities across the distributions of mean household water usage (top panel) and mean parcel vegetation levels (bottom panel). In both cases, estimates for any given percentile are statistically indistinguishable from any other across the entire distribution. Vegetation index models yield a median price elasticity of -1.3 while households at the median of average water usage (184 gallons per day) present an elasticity of roughly -1 that is indistinguishable from those of preferred specifications in Table 3.

5.2 Shifting Price Elasticities Under Drought Policy

I next examine how price-responsiveness of EBMUD customers changed following implementation of the Excessive Use Penalty Ordinance during the height of drought-induced water scarcity. Allowing the price elasticity to vary across periods shows how households' responses to water prices varied under drought policy and water storage conditions. To the extent that households engaged in conservation behavior prior to the start of the EUP, they had likely shifted their consumption to a relatively less elastic portion of the demand curve – resulting in a positive estimate for $\widehat{\Delta \ln(AP)} \times \text{EUP}$. If further behavioral adjustments or structural changes to outdoor irrigation needs took place in response to drought policies, then a similarly positive $\widehat{\Delta \ln(AP)} \times \text{Post-EUP}$ would likely arise. However, if households heeded the end of district and state-level drought emergencies as signs that conservation was no longer necessary, than they could have increased consumption – either relative to during the EUP or even to the pre-policy period.

In Table 5 I report the estimated price coefficients from models following Equation 3. The first row of the top panel reports coefficients for the un-interacted average price simulated instrument, $\widehat{\Delta \ln(AP)}$, reflecting average responsiveness prior to the drought policy period (akin to the pre-drought policy elasticities in Table 3). The second row reports the coefficient estimate for $\widehat{\Delta \ln(AP)} \times \text{EUP}$, reflecting differential price responsiveness while the EUP was in effect. The third row similarly reports the interaction of the price instrument with the post-drought emergency period. The bottom panel reports the overall elasticities for each period and their standard errors.

Column (1) reports estimates from the ordinary least squares model omitting any controls. Column (2) adds weather splines and past consumption controls, while Column (3) includes month-year and Zip-5 fixed effects (event study specification 3) and Column (4) using month-year by Zip-9 fixed effects (specification 4). Column (5) uses the specification of Column (4) but

limits the sample to households that ever use over 1,000 gallons per day. Column (5) restricts the sample to households that violated the Excessive Use Penalty and includes month-year by zip-5 fixed effects to ensure identifying variation is not fully absorbed by controls. As these violating households were the only group subjected to excessive use penalties, their elasticity includes identifying variation around this temporary marginal price tier and provides a valid estimate of plausibly short-run responses.

Results in Column (1) that fail to account for mean reversion or experienced weather yield large magnitude estimates of -1.48 and 1.73 for the pre-EUP price elasticity and the post-EUP elasticity difference, respectively. Estimates in columns (2) and (3) return elasticities of -0.70 prior to the EUP, which attenuate to nearly zero after the policy ends. Both models estimate large, positive, and statistically significant coefficients during the EUP, implying price elasticities during the drought policy period of roughly 1.7 .

Estimates obtained in Column (4) under the preferred control specification mirror long-run elasticity estimates prior to enactment of drought policies. The coefficient of -0.96 on the uninteracted price instrument matches overall pre-drought policy estimates from Table 3. The time period interactions suggest monotonic attenuation over time, with a statistically significant price elasticity of -0.44 during the EUP and an insignificant estimate of -0.16 after its removal. These findings support the notion that after households adopted water conservation practices and district-wide usage fell, they became increasingly less responsive to future price changes.

Columns (5) and (6) illustrate increased pre and post-policy price responsiveness for high usage households, with no conservation impact of price increases for excessive users while drought policies were in effect. When considering only households that ever used an “excessive” volume in Column (5), we observe a pre-EUP price elasticity estimate of -1.24 , larger in magnitude than the overall estimate from Table 3 but smaller than that for all Eastern EBMUD customers from Table 4. The price elasticity falls by roughly half to -0.68 during while the EUP was in effect, and the -0.45 estimate once again becomes statistically indistinguishable from no response once the policy period ends.

Limiting the sample to only ever-treated units that violated the EUP, estimates in Column (6) provide evidence of increased price sensitivity for top water users – except while drought policies were in effect. Prior to experiencing increased prices and fines during the EUP, households that would eventually violate display a price elasticity of -2.23 , over three times as large as the equivalent district-wide average in Column (3). Once the EUP came into effect and these house-

holds experienced moral suasion (and potentially public shaming), their price-responsiveness is weakly statistically significant with a positive overall elasticity of 1.59. This positive elasticity comes about due to a 3.82 difference in elasticities, more than twice the magnitude of policy-period differentials of $1.72 - 1.73$ for all households in Columns (2) and (3). Once the EUP ends, top users' responsiveness falls in line with other high-usage households, with a statistically insignificant post-EUP elasticity of -0.51. This pattern suggests that, when already subject to behavioral policy instruments, excessive use fees did not induce further conservation by violating households.¹⁹

5.3 Price and Non-Price Responses to Drought Policies

I next present results from Eq. 3 in the form of event study figures and aggregate post-treatment effect figures. Event study figures are a common, useful tool for reporting treatment effects and illustrating their evolution over time. A further benefit of event study methods is the avoidance of weighting concerns inherent in typical difference-in-differences estimators (Goodman-Bacon, *in press*) and the ability to aggregate effects to time periods relevant to the research setting. Figures 10-11 show the robustness of estimated effects to alternate control structures and subsamples.

Figure 9 plots the moral suasion and public shame event studies for the preferred specification following Eq. 3. The blue points and band in the top panel correspond to the event-time coefficient estimates and 95% two-way clustered confidence intervals for moral suasion exposure. In the bottom panel, the red points and band report the public shaming event-time effects from the same model. As the event-time coefficient $\hat{\tau}^k$ measures the annual change in log gallons per day due to being k billing cycles since treatment, it can be interpreted as a semi-elasticity and reports the average percentage annual change in water use relative to the billing cycle prior to treatment ($k = -1$). A coefficient equal to zero conveys that treated units experienced no difference in their annual change in water use relative to their pre-treatment cycle while a coefficient of -20% indicates that water use fell by 20% on average among treated homes k periods after first exposure relative to control households.

Turning first to moral suasion in the top panel, we observe delayed conservation responses that die out within a year and a half. Annual changes in water use prior to treatment for violating

19. Equivalent estimates obtained using month-year by Zip-9 fixed effects are highly similar but much noisier and yield coefficients and standard errors of -2.61 (2.19) for $\Delta \widehat{\ln(AP)}$, 4.24 (1.74) for $\Delta \widehat{\ln(AP)} \times \text{EUP}$, and 1.52 (2.18) for $\Delta \widehat{\ln(AP)} \times \text{Post-EUP}$.

households consistently appear slightly higher than in control households, ranging from 0 and 15%. When a violation first occurs the gap between violating and control households grows to 52.5% at event time 0, suggesting that violation is correlated with a particularly large water shock or outlier use period. This effect falls to 26% and 4% over the following two billing cycles before turning negative in event time 3. Treatment effects grow in magnitude from -9% to -16% between event times 3 and 5 (6 and 10 months post-treatment) before reaching a maximum change of -67% after 12 months ($k = 6$). The moral suasion effect reduces in magnitude to -43% at event-time 7 with estimates for all future periods even smaller in size and often statistically indistinguishable from zero.

Public shaming displays a larger magnitude but similarly short-run conservation response. Pre-treatment event time indicators in the bottom panel are largely statistically indistinguishable from zero, with point estimates oscillating around zero with little clear pattern. Water use spikes by 69% at event time $k = -2$, suggesting that eventually-shamed households engaged in trend-deviating activity in the months shortly before their first shaming (and likely prior to their first EUP violation). Once public shaming occurs, we observe a negative but statistically insignificant point estimate for the billing cycle during which shaming occurs ($k = 0$), reflecting the partially-treated nature of that cycle. Estimates remain negative but statistically indistinguishable through then next six months (through event time $k = 3$). Water usage declines further over the next six months post-shaming, with statistically significant reductions of 36%, 71%, and 60% estimated for billing cycles 8, 10, and 12 months after shaming, respectively. Once again, additional conservation effects of public shaming disappear shortly after the EUP ends, with the coefficient for 14 months after first exposure ($k = 7$) losing all significance and jumping to a small, positive value. Coefficients for future periods are similarly indistinguishable from no difference relative to control households.

The disappearance of treatment effects shortly after district-wide conservation policies end confirm the observed patterns in overall consumption changes. Figure 6 showed that average residential water consumption fell substantially as drought severity grew, even before the EUP came into effect. Consumption further fell during the EUP period among both violating and non-violating households. In contrast, consumption patterns largely stabilized once the drought emergency was lifted. At that point, consumers were no longer inundated with messaging to conserve – both from the district and at the state-level (California’s drought emergency ended in April 2017). The signaling of crisis by the water district and the risk of future public shaming

for high-usage households both ended once drought policies were abolished. As a result, the welfare costs to these top users of maintaining greater reductions in water use relative to their neighbors largely disappeared and prompted a return to more typical consumption patterns.

5.3.1 Robustness of Behavioral Responses

To explore the robustness of estimated treatment effects for moral suasion and public shame, I next present estimates of average first-year treatment effects across a range of specifications and sub-samples. Figures 10 and 11 plot average first-year treatment effects on the treated and 95% confidence intervals clustered by 9-digit zipcode and fiscal year for the full analysis sample (“Full,” $N = 8.8M$) and four progressively smaller samples of control households: those in 5-digit zip codes bisected by an elevation band (“Band Split,” $N = 7.0M$), that ever used over 1,000 gallons per day in a billing cycle (“Ever 1K+,” $N = 1.1M$), that average at least 1,000 gallons per day (“Avg 1K+,” $N = 163K$) and only those that violated the Excessive Use Penalty (“EUP,” $N = 149K$) without never-treated units.

For each set of control households I report estimates from left to right for four sets of increasingly conservative model specifications. The first column omits weather controls and all fixed effects from Eq. 3 and is akin to a household-level fixed effects model that does not control for past consumption. The next specification includes weather splines and past consumption controls, and specifies δ_{zt} as month-year fixed effects. The third column adds Zip-5 fixed effects, while the fourth column utilizes month-year by Zip-9 fixed effects and matches the specification of Figure 9.

Moral suasion results in Figure 10 show stability of first-year ATTs across the first four sub-samples with the largest effects estimated when considering only the households that violated the EUP. Ordinary least squares estimates with no controls (left-most estimates) are highly stable across samples, ranging between -16% and -21% with no ability to statistically distinguish any of the point estimates from one another. The three increasingly-conservative control structures also return highly stable estimates for samples that include never-treated units: estimated average first-year effects fall between -10% and -28% across all specifications and between -10% and -17% for the preferred month-year by Zip-9 fixed effects model. These estimates correspond to average reductions 10-28% greater for households exposed to moral suasion in the year following EUP violation in comparison to never or not yet-treated households.

First-year conservation effects of moral suasion grow substantially when the sample is limited

to EUP violators. When only identifying off comparisons between currently and not yet-treated households, moral suasion ATTs increase in magnitude to -49% to -58% when models include controls. The -58% effect for the preferred month-year by zip-9 fixed effects specification (farthest right) is statistically distinguishable from equivalent models run on the full, band split, and ever over 1,000 gallons per day samples (but is indistinguishable from the average 1,000 gallons per day sample estimate of -17%). This increase in effect magnitude suggests that never-treated households decreased their water usage during the EUP at faster rates than households who eventually violate the ordinance, resulting in attenuated first-year treatment effect estimates in models that include pure control units.

Public shame results in Figure 11 provide evidence of increased stability across samples and confirm the effectiveness of public shaming on inducing additional conservation beyond those elicited by fees or moral suasion. Estimated first-year treatment effects on the treated are statistically indistinguishable across samples and specifications with estimated changes in water use ranging from -14% to -32%. These estimates indicate that publicly shamed households further increased the magnitude of their water reductions in comparison to control households for the twelve months following being called out in the local news.

While estimates are within 3 percentage points of each other for the full and band split samples, estimates from the most conservative control specification become smaller in magnitude and more noisy as the sample sizes decrease. This attenuation and increased variance likely arise from the low number of households now identifying each fixed effect. When the sample is reduced to only EUP violators, 2,300 out of 3,189 9-digit zip codes only ever contain one household – with 2,817 containing fewer than three households.²⁰ As a result, all identifying variation for 17 out of 56 shamed households (and 2,283 unshamed EUP violators) will be fully absorbed by the month-year by Zip-9 fixed effects.

5.4 Comparison of Responses to Price and Non-Price Drought Policy Instruments

To better understand which policy instruments are well-suited to short or long-run conservation policies, I next explore how the conservation effects of non-price behavioral drought policies compared to consumers' responses to price changes. Combining price elasticity estimates from

20. In contrast, 39,845 out of 54,588 9-digit zip codes in the full analysis sample contain 3 or more households. Only two of these singleton-household zip codes contain a publicly shamed account.

Tables 3 and 5 with first-year responses to moral suasion and public shame from Figures 10-11, I calculate the additional short-run price changes that would have been necessary to match behavioral responses to non-price drought policy instruments.

Table 6 reports the implied price increases necessary to match households' average first-year response to moral suasion and public shame exposure across a range of samples and price elasticities. Models (1)-(3) utilize behavioral first-year ATTs from the fourth “Full” sample estimate in Figure 10 that includes weather splines, past consumption controls, and month-year by 9-digit zipcode fixed effects. These models use price elasticities from Column (4) of Table 3 and calculate necessary price increases using price elasticities before, during, and after the EUP policy period, respectively. In this way Model (1) reflects the price increase necessary if households were to return to consumption behavior observed before extensive drought reductions, while Model (3) reflects typical post-drought behavior.

Models (4)-(5) focus on the responsiveness of higher usage households during the drought policy period, using estimates for households that ever used over 1,000 gallons per day (“Ever 1K+”) or violated the Excessive Use Penalty (“EUs”), respectively.²¹ Calculations for moral suasion are reported in the top panel while the bottom panel repeats the calculations for responses to public shame.

Turning first to the top panel of Table 6, we see increasingly large price changes necessary to match responses to moral suasion as households adapted to drought. Model (1) calculations show that a relatively modest average price increase of 11% could have induced similar water use reductions as the first-year effect of moral suasion if households returned to their pre-drought price elasticity of -1.09 . However, this necessary increase grows substantially in magnitude as households adapt to drought and shift to less elastic regions of the demand curve. The average price increase of 30% for all single family home customers in Model (2) reflects the much-attenuated price elasticity of -0.435 observed during the height of drought. Once the EUP period ended and price elasticities fell further to -0.159 , I find that prices would have had to more than double, with an increase of 107% needed to match moral suasion’s impact.

Turning to Models (3)-(4), we see a stark difference in necessary price changes when considering potential versus actual EUP violators. Back-of-the-envelope calculations for households that ever used above the EUP threshold in Model (3) suggest a price increase of 15% to match

²¹ While Model (3) follows the specification of Models (1)-(2), calculations for excessive use violators in Model (4) include month-year and 5-digit zipcode fixed effects in place of the interacted fixed effects to ensure sufficient identifying variation. See the discussion at the end of Section 5.3 for more details.

price responsiveness while policies were in effect. Shifting to the set of households that actually violated the policy in Model (4), we see that no price increase could induce short-run conservation behavior given the large and positive short-run price elasticity (1.587). This finding suggests that excessive use fees primarily functioned as a short-term revenue source rather than as an instigator of conservation behavior among the highest-use households.

Looking to the bottom panel for price increases needed to match responses to public shame, we observe similar patterns at generally higher magnitudes. Full sample models imply necessary average price increases of 32% under pre-drought price sensitivity, 101% for conditions while drought policies were in effect, and 574% after drought emergencies ended. Models limiting control households to those that ever used “excessive” volumes during the entire sample period suggest average price hikes of 40.6% during the EUP. Once again, considering only ever-treated households who violated the policy yields no conservation ability of short-run price changes during the EUP.

These findings suggest that feasible price changes during drought crisis likely would not have resulted in comparable conservation effects as moral suasion and public shame combined. When considering observed price responsiveness for all households during the policy period, these non-price instruments induced conservation on par with a short-run sextupling of average prices – an infeasible change in nearly all conceivable settings and policy contexts. Although considering elasticities for general high-usage households reduces this total price change to 56%, the top users actually exposed to excessive use fees showed no price-based conservation response while simultaneously exposed to both non-price policy instruments.

This result of limited power for feasible short-run price increases to induce conservation during extreme drought mirrors existing findings across a broad set of prior price instruments and drought conditions. Doubling the marginal price faced by high-usage households during a prior drought in Santa Cruz, CA resulted in a 12% reduction in water used by treated households (Nataraj and Hanemann 2011). Similarly, a 52% increase in average price was needed to match conservation impacts of mandatory use restrictions in North Carolina (Wichman, Taylor, and von Haefen 2016). Perhaps the most comparable policy occurred a year before the EUP in Santa Cruz, CA. In 2014, Santa Cruz Municipal Utilities imposed excessive use fees that increased average prices by 54-299% for consumption over 125 gallons per day. While nearly 14% of residential customers received at least one fine, aggregate water use fell by only 5-10% as a result of these fines and broader social pressure (Pratt, [in press](#)). These findings suggest that

price-based conservation would likely not have matched responses to non-price instruments even if EBMUD had set the excessive use threshold at a much lower point in the water distribution.

6 Conclusion

In this paper I take advantage of unique variation in price to estimate causal price elasticities and separately identify excessive users' responses to price and non-price water conservation policies during recent extreme drought in the San Francisco East Bay Area. Using administrative data for the universe of residential water users in a major California water district, I estimate medium to long-run price elasticities of -0.97 to -1.09 prior to the imposition of conservation-oriented drought regulation. I find that price elasticities are largest under conditions prompting the highest levels of outdoor irrigation and for high-usage households. However, residential price responsiveness attenuates substantially over time as households adopt conservation behavior and reduce non-essential outdoor use. The employed simulated instrument approach builds upon previous causal water demand estimation strategies by eliminating mean reversion and distributional shifts as potential sources of bias. Further, estimates prove highly robust to the choice of price measures and control approaches.

Models focused on responses to price and non-price drought policies provide the first empirical evidence of public shame's effectiveness at inducing resource conservation. Moreover, I separately identify responses to public shame from changes due to excessive use fees or moral suasion messaging. I find evidence of sizable short-run conservation due to behavioral instruments but no comparable response to price changes. In the year following exposure to moral appeals to conserve, treated households reduced water consumption by 10-50% relative to control units. Households that were publicly shamed after moral suasion exposure demonstrate additional conservation, further reducing water use by 23-30%. In contrast, I estimate a large, positive price elasticity for excessive users exposed to short-run increases to marginal price. Back-of-the-envelope calculations imply that drought policies would have had to increase average prices by an additional 11-32% to match conservation responses to either moral suasion or public shame alone given overall pre-drought elasticities. This necessary price change grows to 30-574% when considering overall price responsiveness during or following drought policies. Importantly, no further price increase could have prompted additional conservation from top water users who violated the drought usage threshold.

Taken together, these findings convey important policy implications for the design of future urban water conservation policies. In my setting, price-based policies proved most effective at inducing long-run adaptation behavior and had the least power at affecting short-run, discrete reductions among top water users. Early on in the sample, price-based policies proved effective at driving adaptation behavior as drought conditions grew more severe. Further, prices showed the greatest ability to reduce non-essential, outdoor irrigation over several years of increasing water scarcity. However, financial incentives displayed substantially lower effectiveness at driving short-run, discrete reductions in response to acute shortages, as households had already eliminated many non-essential water uses and adjusted along the most promising conservation margins. This is especially true among top water users who displayed no conservation response to excessive use fees while already exposed to behavioral policy measures. However, these same users showed the greatest price-responsiveness post-drought emergency – suggesting that price-based policies targeting gradual reduction of outdoor water uses could still prove valuable for adjusting to changing water supply equilibria.

In contrast, moral suasion and public shamed proved both highly effective at driving discrete, short-run conservation and fully reliant on consumer belief in crisis. Together, moral suasion and public shame reduced consumption among the highest-usage households by 40-70% for nearly a full year at the peak of the drought emergency. However, once the district ended its drought emergency, the messaging these households faced shifted to one of a wet winter and sufficient supplies to more than meet essential needs. At that point all conservation effects from prior exposure to moral suasion and public shame disappeared – indicating that households stopped responding as soon as they no lost belief in the moral need to conserve. This lack of long-run response mirrors prior findings of residential water and energy users' habituation to moral conservation appeals (Ferraro, Miranda, and Price 2011; Ito, Ida, and Tanaka 2018) and extends the conclusion to the case of public shaming.

Future research can continue to improve our estimation of residential water demand and to identify the impacts of non-price policy mechanisms for eliciting conservation behavior. Uncovering plausibly causal price elasticities in additional settings will provide a foundation for improving the targeting of price-based policies and designing rate structures that can balance long-run conservation goals with legal constraints. Studies that explore the extent to which behavioral measures crowd out price responses in the short and long-run will help water districts improve the design of future conservation policies. Further, understanding how pricing

strategies interact with various short-run drought policies can both guide the choice of optimal rate structures and increase our understanding of the equity implications of various approaches. Research providing such insights has the potential to improve the reliability and availability of urban water around the globe and help reduce a major obstacle to the continued success of modern urban societies.

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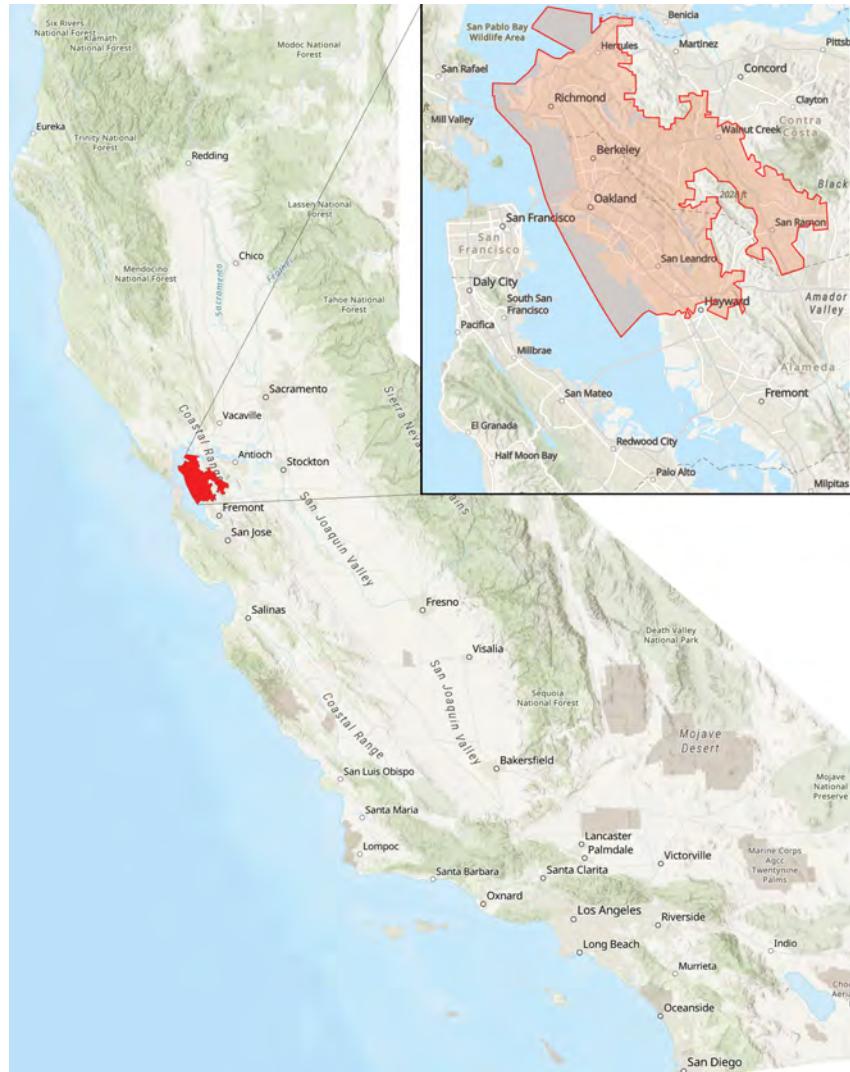


Figure 1: East Bay Municipal Utility District (EBMUD) service area. This figure plots the location of the EBMUD service area in California. The inset map in the upper-right corner provides a zoomed-in view of San Francisco’s East Bay Area and shows the EBMUD water service area in red (shape files obtained from EBMUD).



1-866-40-EBMUD

YOUR ACCOUNT NO. IS:

12345678001

Effective July 1, 2015 new rates are in effect to pay for replacement of aging pipelines and long-term infrastructure improvements. To fund increasing drought costs, a temporary 25% drought surcharge is in effect. Excessive use penalties will apply to residential customers averaging more than 984 gallons per day. For more information visit www.ebmud.com

 Florence Waters 1234 PIPELINE ST OAKLAND CA 94607-1234	Bill Date:	09/03/15					
	Billing Period						
	From 07/01/15	To 09/01/15					
For: 1234 Pipeline St Private Residence	AMOUNT	TOTAL					
WATER CHARGES - EBMUD							
WATER SERVICE CHARGE	38.68						
WATER FLOW CHARGE	44.25						
15 UNITS @ 2.95							
18 UNITS @ 4.06	73.08						
87 UNITS @ 5.38	359.12						
WATER ELEVATION CHARGE	60.00						
100 UNITS @ 0.60							
DROUGHT SURCHARGE	115.55						
EXCESSIVE USE PENALTY	40.00	730.68					
PLEASE SEE REVERSE SIDE FOR BILLING EXPLANATION	Please Pay This Amount Now Due	892.47					
METER SIZE	ELEV. Band	METER READINGS	CONSUMPTION INFORMATION				
5/8 inch	2	Current 2,197 2013	Previous 2,097 USAGE	UNITS 100 125	Gallons 74,800 93,500	Days 62 63	Gal/Day 1,206 1,484

Figure 2: East Bay Municipal Utility District (EBMUD) Excessive Use Penalty bill (Source: EBMUD). This figure shows a copy of a residential water bill for an EBMUD households that violated the Excessive Use Penalty and faced penalty fees in addition to drought surcharges and typical marginal prices and service charges.

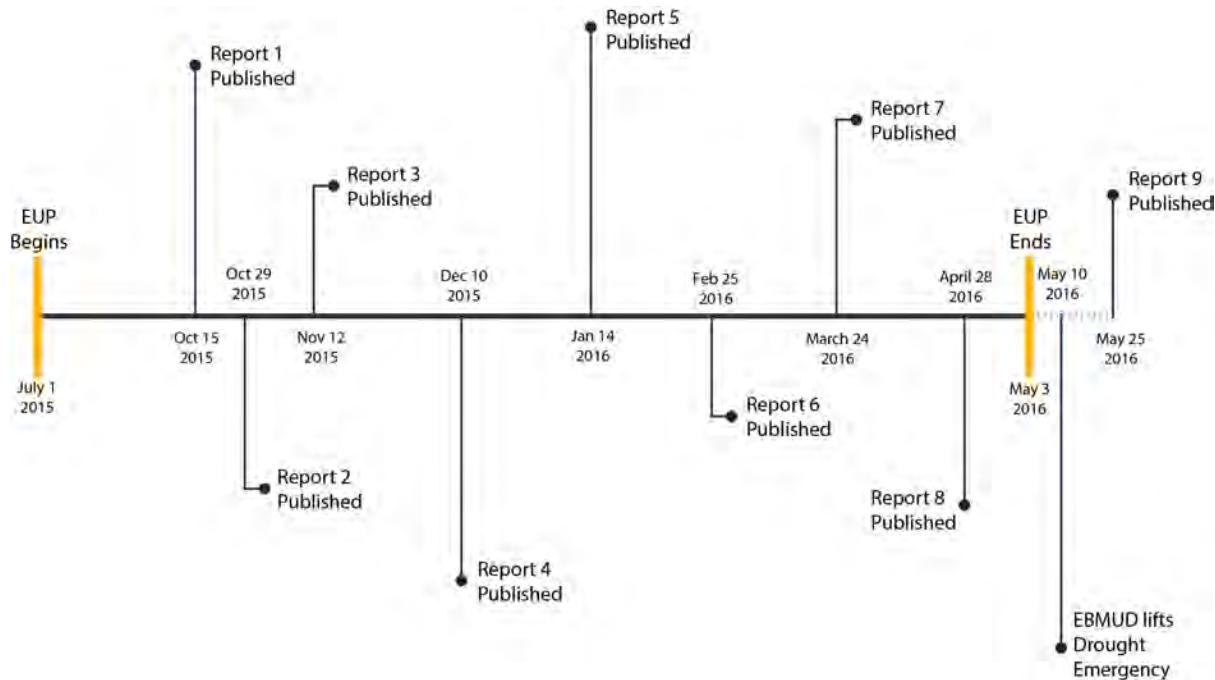


Figure 3: Excessive Use Penalty Ordinance Timeline. This figure provides a timeline of the East Bay Municipal Utility District's Excessive Use Penalty Ordinance (EUP) during the height of the 2011-2017 California drought.



DROUGHT

EBMUD releases list of excessive water users



(a) Source: ABC Channel 7 News

EBMUD Provides Records Identifying 1,108 Excessive Water Users

Seventeen Pleasant Hill residents made the list. Are any your neighbors?

And at the top of the list was [REDACTED] of Danville, a former [REDACTED] executive who used 12,579 gallons per day. Many of the households that violated the ordinance were in East Bay communities with larger properties, Figueroa said, such as Danville and Alamo. EBMUD expected that would be the case.

The top Pleasant Hill water user is [REDACTED]

(b) Source: Patch.com

Figure 4: Public Shaming of Excessive Water Users. These figures provide examples of news articles calling individual water users out by name after violating the Excessive Use Penalty Ordinance. Figure 4a shows a story calling out an individual of local relevance, while Figure 4a shows users being shamed for using the most water on a given monthly report or for a given city.

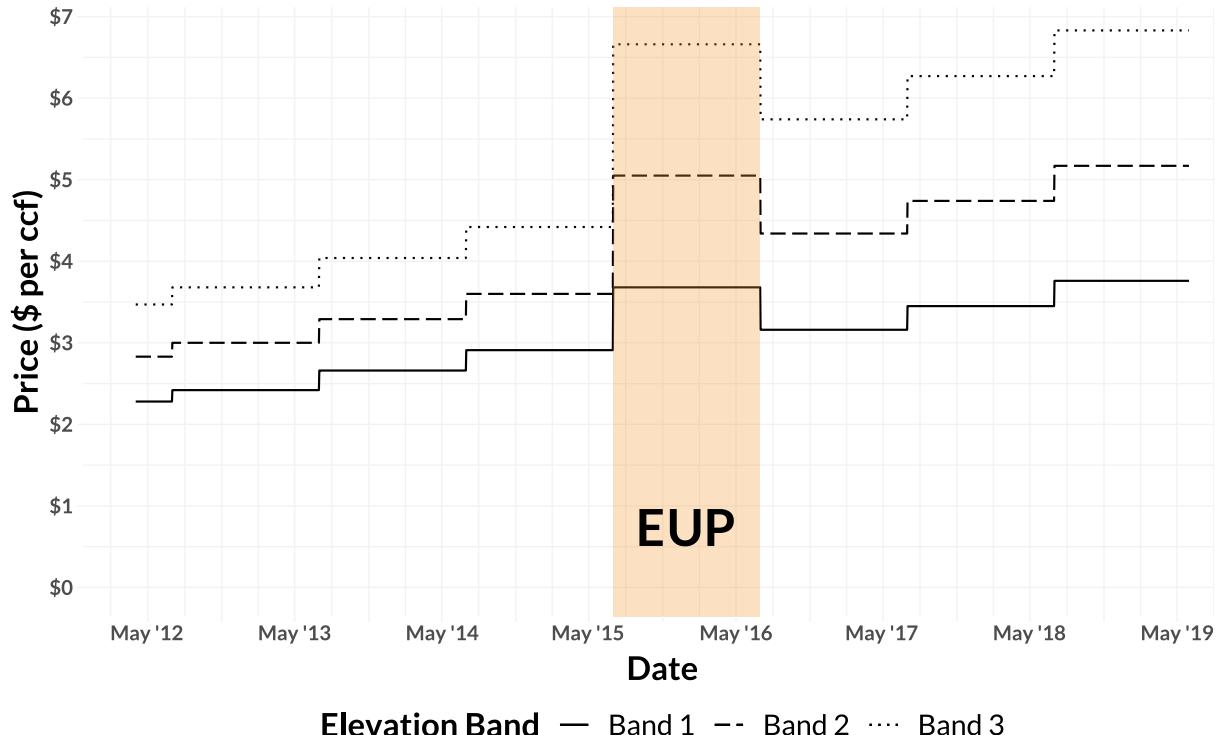


Figure 5: Variation in Tier 1 Marginal Prices. This figure plots variation in marginal prices across time and space for a median consumption household (in marginal price tier 1). The solid line reports the marginal price of tier 1 consumption over time for households in the base elevation band 1 who face no elevation surcharges. The dashed line reports the marginal price for a household located in elevation band 2 (approximately 200-600 feet above sea level) consuming an identical volume of water. The dotted line reports marginal prices for homes in elevation band 3 (approximately 600+ feet above sea level).

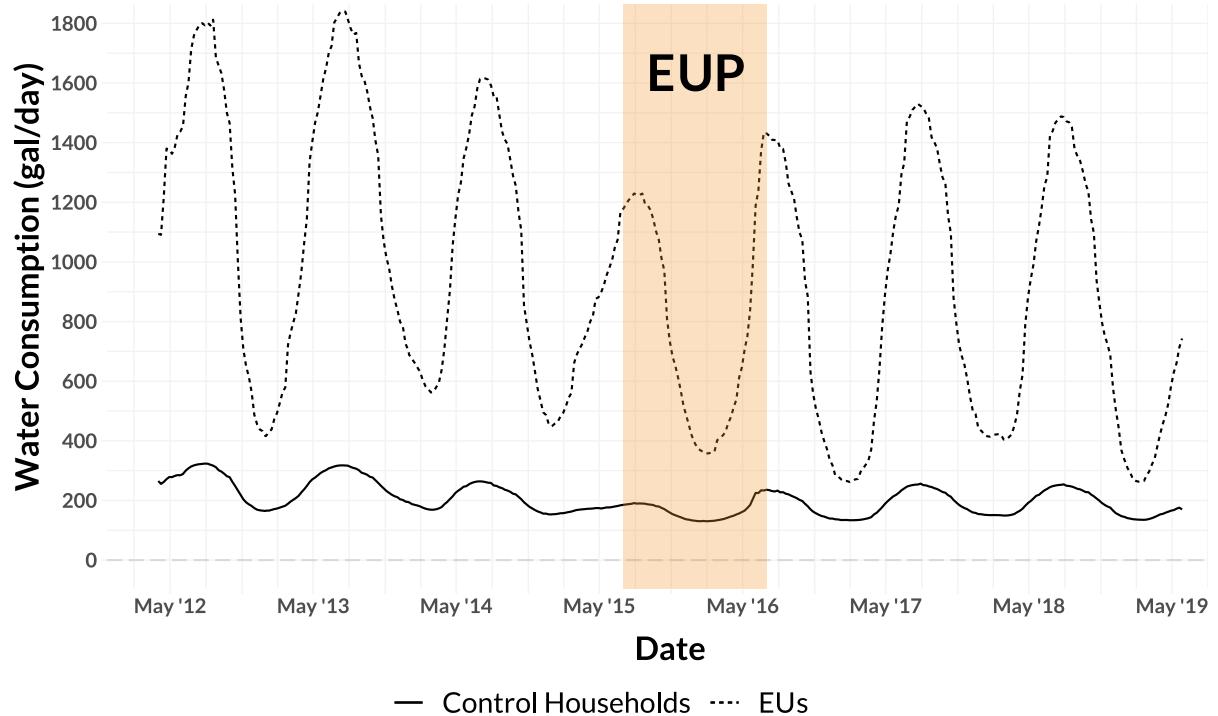


Figure 6: Average water use over time by EUP violation status. This figure plots the average water use measured in gallons per day for all single family homes in the EBMUD service area from April 2012 through May 2019. The dotted line reports the average usage for customers that violated the EUP while the policy was in effect (indicated by the orange band) and were exposed to fees, moral suasion, and potentially public shame (“EUs”). The solid line reports mean water use for all other detached single family home EBMUD customers that were not directly exposed to EUP policy instruments (“Control Households”).

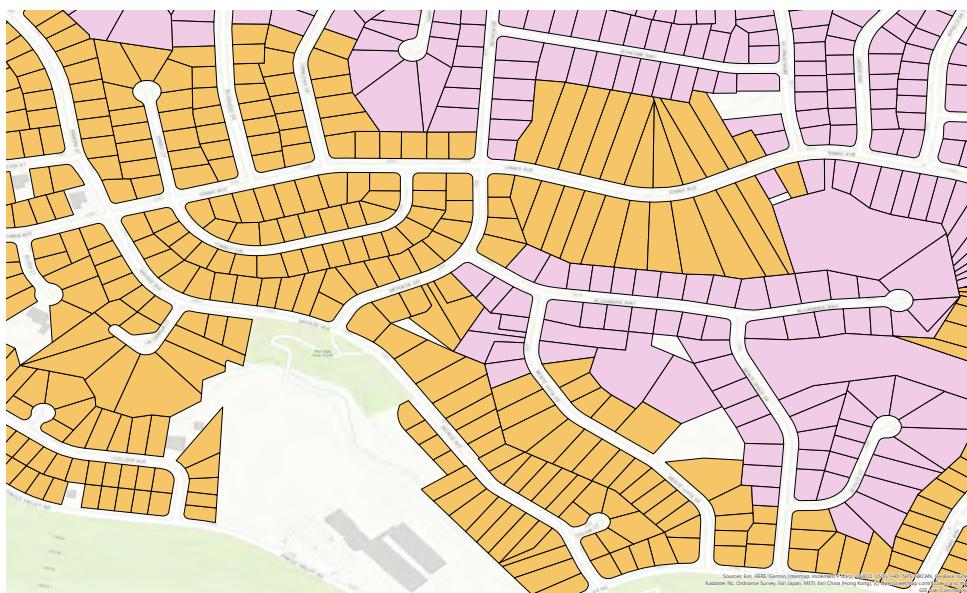


Figure 7: Example of the elevation band threshold between homes in band 1 (Orange) who face no elevation surcharges and in band 2 (Pink) who pay higher marginal prices across all consumption tiers.

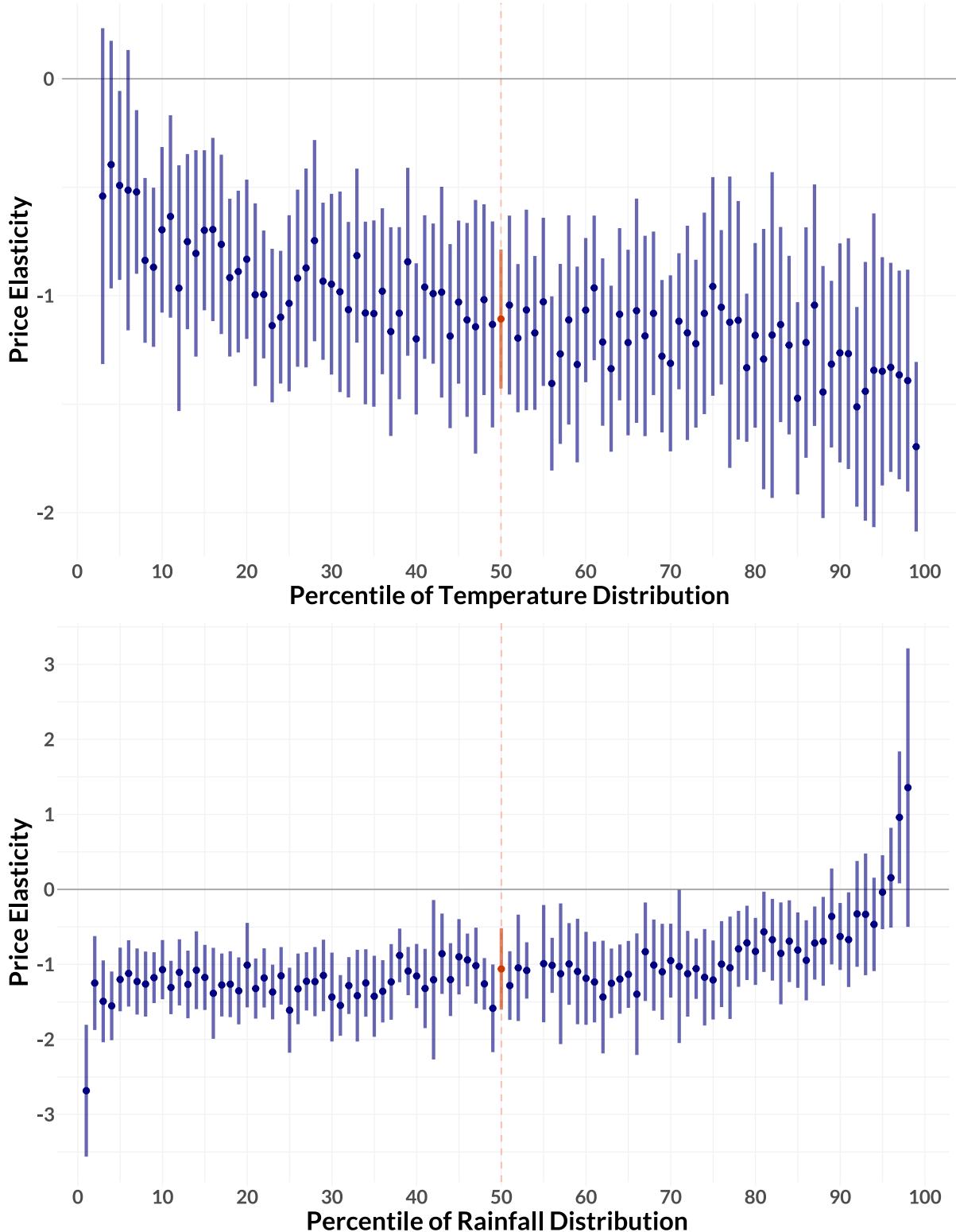


Figure 8: Price elasticity heterogeneity by billing cycle weather. This figure plots the coefficients and 95% confidence intervals for the overall price elasticity at each percentile of growing degree days (top panel) and precipitation (bottom panel). Estimates are obtained using models that follow Eq. 1 where the price instrument is interacted with each percentile of a given variable's distribution. Each point estimate is calculated as the sum of the percentile's interaction term and the coefficient on the baseline term (50th specified as the omitted group) with the standard error of the sum calculated from the relevant components of the variance-covariance matrix.

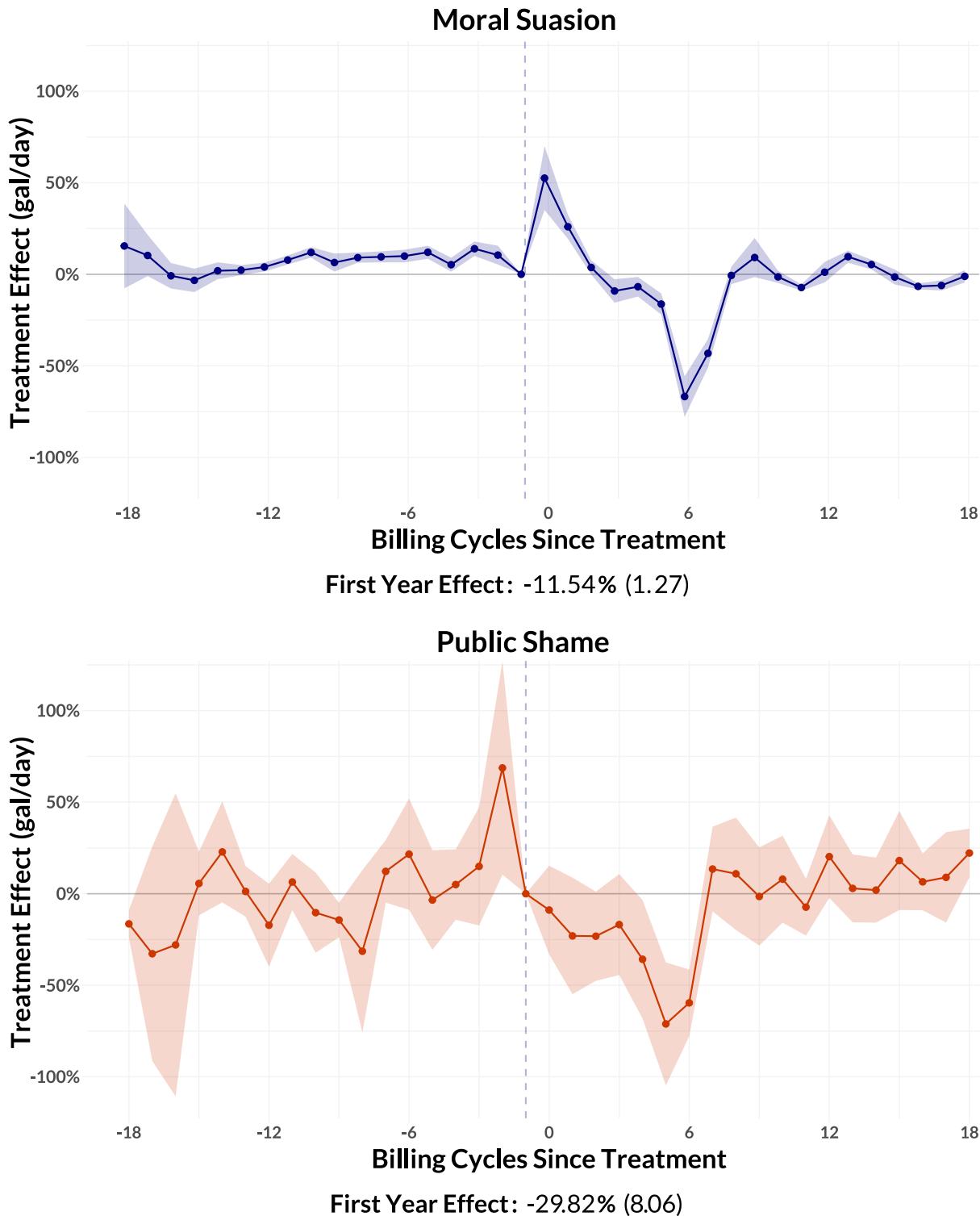


Figure 9: Moral Suasion and Public Shame Event Study. This figure reports event-time coefficient estimates and 95% standard errors clustered by Zip-9 and fiscal year for exposure to moral suasion (top panel, blue) and public shame (bottom panel, red) obtained using Eq. 3. The model is estimated in annual differences and includes month-year by Zip-9 fixed effects and controls for underlying shifts in the water use distribution with interactions of the month-year with each percentile of water use six months' prior. “First Year” effects report the average treatment effect in the first year post-treatment.

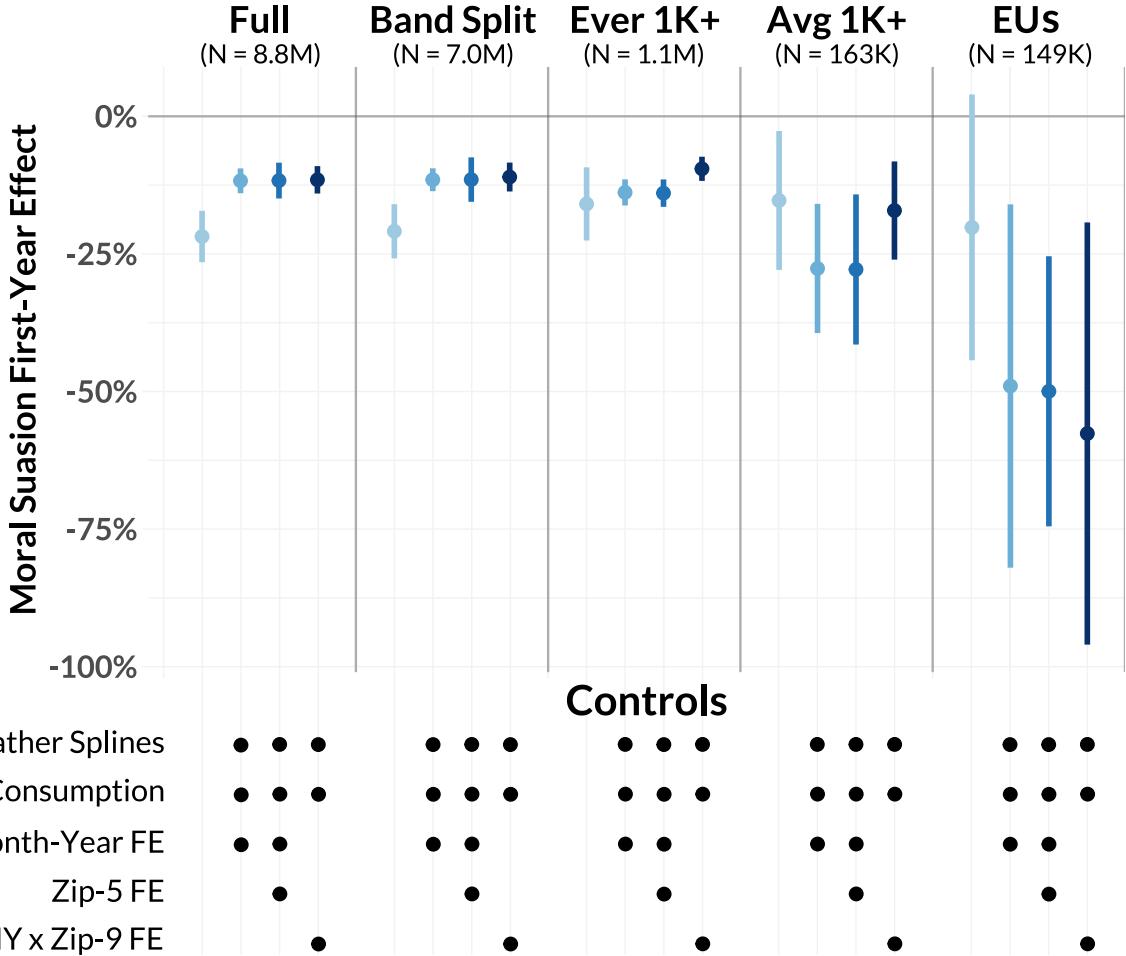


Figure 10: First-Year Effects of Moral Suasion. This figure plots point estimates and 95% confidence intervals clustered by Zip-9 and fiscal year for the average response to moral suasion for each billing cycle in the year after first exposure ($1 \leq k \leq 6$). “Full” denotes the entire analysis dataset ($N = 8.8M$) while “Band Split” limits control households to those living in 5-digit zipcodes bisected by an elevation band ($N = 7.0M$), “Ever 1K+” to households who use over 1,000 gallons per day in at least one billing cycle ($N = 1.1M$), and “Avg 1K+” to accounts that average at least 1,000 gallons per day ($N = 163K$). “EUs” includes only households who violated the EUP (and are included in all other sub-samples).

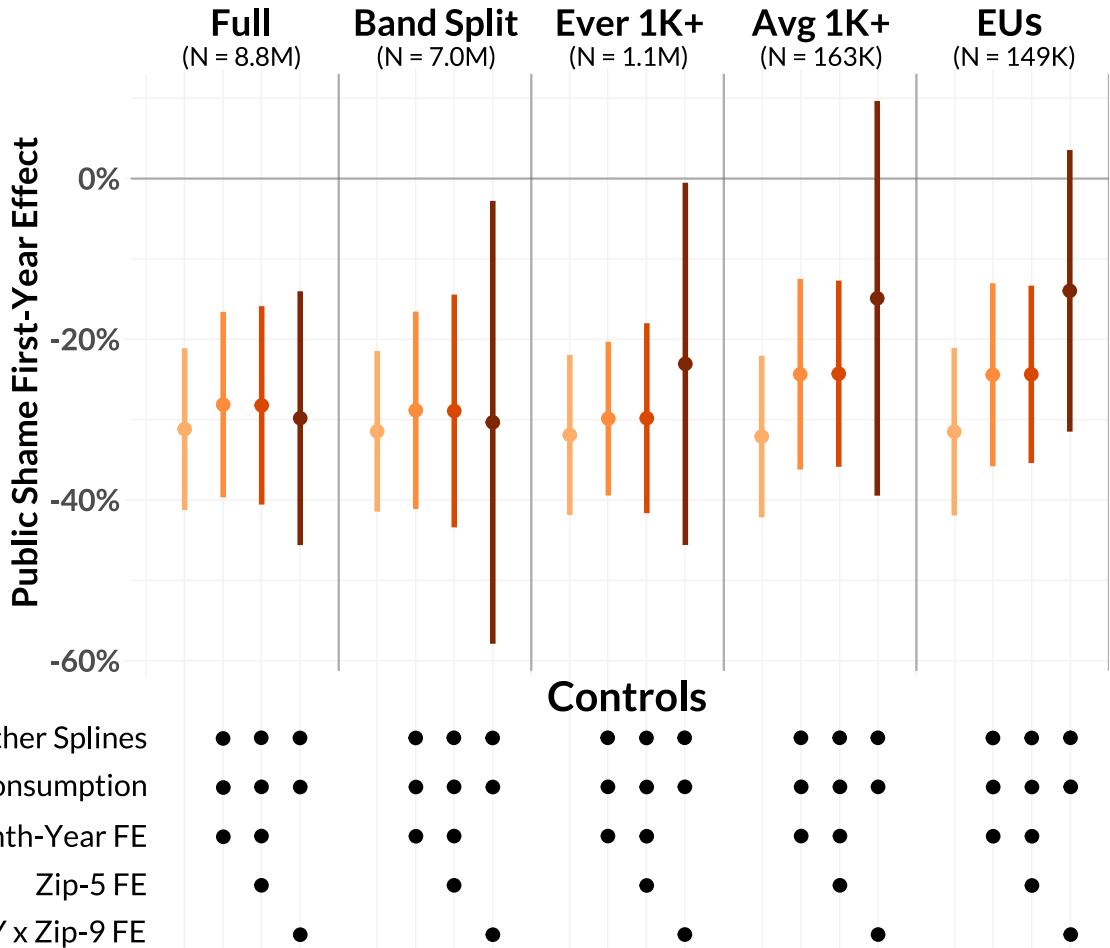


Figure 11: First-Year Effects of Public Shame. This figure plots point estimates and 95% confidence intervals clustered by Zip-9 and fiscal year for the average response to public shame for each billing cycle in the year after first exposure ($0 \leq k \leq 5$). “Full” denotes the entire analysis dataset ($N = 8.8M$) while “Band Split” limits control households to those living in 5-digit zipcodes bisected by an elevation band ($N = 7.0M$), “Ever 1K+” to households who use over 1,000 gallons per day in at least one billing cycle ($N = 1.1M$), and “Avg 1K+” to accounts that average at least 1,000 gallons per day ($N = 163K$). “EUs” includes only households who violated the EUP (and are included in all other sub-samples).

Table 1: California Water District Policies During Drought Crisis

Policy Instrument	Water Districts
Education campaigns	El Dorado, El Centro, Imperial, Placer
Rebate programs	Calaveras, Folsom, Sacramento, Yuba City
Drought Surcharges	Contra Costa, Irvine, LA
Increasing Block Fees	Citrus Heights, Coachella
Contact high users	Anaheim, LA, Milpitas, Morro Bay, Turlock
“Excessive use” fines	Apple Valley, San Jose, Santa Cruz

This table reports examples of the main policy instruments implemented during the height of California’s 2011-2017 drought for a subset of the states’ water districts.

Table 2: Summary Statistics, Billing Cycle Characteristics

	Full Sample		Excessive Users	
	Mean	Std. Dev.	Mean	Std. Dev.
Water Volume (CCF)	18.010	21.804	82.932	79.273
Days per Billing Cycle	60.172	5.737	60.072	6.171
Gallons per Day (GPD)	225.385	280.344	1,041.979	1,001.662
‘Excessive’ Use (\$1,000+\$ GPD)	0.019	0.136	0.409	0.492
Ever Used \$1,000+\$ GPD	0.124	0.329	1	0
Marginal Price (\$/CCF)	3.761	1.069	5.956	1.680
Average Price (\$/CCF)	7.593	4.927	6.108	2.292
Total Bill Amount (\$)	104.674	126.582	501.627	550.458
Elevation Band 2 (\approx 200-600ft)	0.363	0.481	0.615	0.486
Elevation Band 3 (\gtrsim 600ft)	0.095	0.293	0.297	0.457
Lot Size ¹ (acre)	0.147	0.226	0.520	1.412
Home Size ¹ (ft ²)	1,842.858	894.296	3,856.909	1,642.458
Growing Degree Days	311.669	177.409	306.397	216.236
Total Precipitation (mm)	95.657	119.410	102.662	129.834
Observations	10,709,816		184,637	
Households	301,271		4,951	

This table reports summary statistics of billing cycle characteristics for the analysis sample. “Full Sample” columns report the mean and standard deviations of billing cycle characteristics for all households while “Excessive Users” reports values only for households that violated the Excessive Use Penalty Ordinance by using over 1,000 gallons per day in a billing cycle while the policy was in effect. “Excessive Use” is a dummy variable equal to one for any billing cycle with water use over 1,000 gallons per day and “Ever Used (1,000+ GPD)” is a dummy variable equal to one in all billing cycles for customers that ever use over 1,000 gallons per day in a single period. All prices are deflated using the U.S. Bureau of Economic Analysis’ Implicit Price Deflator. ¹ home characteristics are matched for only 7,454,864 observations.

Table 3: Pre-Drought Policy Water Demand Estimates

Average Price Models	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln(AP)$	-1.622*** (0.021)	-1.660*** (0.017)				
$\Delta \widehat{\ln(AP)}$			-1.110** (0.148)	-1.093*** (0.106)	-1.090*** (0.152)	-1.046*** (0.152)
$\Delta \widehat{\ln(AP)} \times$ Ever Excessive						-0.342 (0.242)
Marginal Price Models	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln(MP)$	2.521*** (0.099)	2.546*** (0.106)				
$\Delta \widehat{\ln(MP)}$			-1.024* (0.323)	-0.967** (0.111)	-1.074*** (0.151)	-1.024*** (0.152)
$\Delta \widehat{\ln(MP)} \times$ Ever Excessive						-0.3449 (0.243)
Month-Year \times Zip-9 FE	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	Yes	Yes	Yes	Yes	Yes
Past Consumption Controls	No	No	No	Splines	MY \times Pctl	MY \times Pctl
Observations	2,925,167	2,925,167	2,925,167	2,925,167	2,925,167	2,925,167
# Month-Year \times Zip-9 FE	646,124	646,124	646,124	646,124	646,124	646,124
Adjusted R ²	0.680	0.699	0.117	0.118	0.121	0.121

* p < 0.10, ** p < 0.05, *** p < 0.01. Standard errors are two-way clustered by fiscal year and 5-digit zipcode. These models estimate the pre-drought average and marginal price elasticities of residential water demand for detached single-family homes in the San Francisco East Bay Area using data from April 1, 2012 through July 28, 2015. The dependent variable $\Delta \ln(Q)$ measures the change in the log of gallons per day by a household between the current billing cycle and the same period in the previous year. In the top panel $\Delta \ln(AP)_{it}$ is the equivalent change in the log of average price, and $\Delta \widehat{\ln(AP)}$ is the simulated price instrument using consumption levels from six months earlier. The bottom panel reports estimates for identical specifications that use the corresponding marginal price measure in place of average price. *Weather Controls* include cubic splines in growing degree days and total precipitation per billing cycle, with knots at each decile of the variables' distributions. *Past Consumption* controls of "Splines" employ a cubic spline approach for household consumption six months prior akin to weather controls, while "MY \times Pctl" indicates percentiles of consumption six months prior interacted with the month-year (2,905 fixed effects).

Table 4: Pre-Drought Policy Price Elasticity by Season and Location

	Season				Hills Location	
	Spring (1)	Summer (2)	Fall (3)	Winter (4)	West (5)	East (6)
$\widehat{\Delta \ln(AP)}$	-1.063 (1.226)	-1.087*** (0.1148)	1.213* (0.9187)	-1.047 (7.837)	-0.8206*** (0.2214)	-1.446*** (0.2081)
$\widehat{\Delta \ln(AP)} \times$ Ever Excessive	-0.4907*** (0.2114)	-0.3593*** (0.1471)	-0.2904 (0.4117)	-0.3263 (0.4298)	-0.2535 (0.2963)	-0.3978* (0.2543)
Weather Splines	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year \times Zip-9 FE	Yes	Yes	Yes	Yes	Yes	Yes
Past Consumption Pctl. \times Zip-9 FE	Yes	Yes	Yes	Yes	Yes	Yes
Mean GPD	244	334	269	181	187	412
Observations	726,556	727,843	729,566	682,318	2,018,587	906,580
Adjusted R ²	0.100	0.071	0.139	0.149	0.082	0.192

* p < 0.10, ** p < 0.05, *** p < 0.01. Standard errors are two-way clustered by fiscal year and 5-digit zipcode. These models estimate the pre-drought policy price responsiveness of residential water demand for detached single-family homes in the San Francisco East Bay Area using data from April 1, 2012 through July 28, 2015. The dependent variable $\Delta \ln(Q)$ measures the change in the log of gallons per day by a household between the current billing cycle and the same period in the previous year. $\Delta \ln(MP)_{it}$ is the equivalent change in the log of marginal price, and $\widehat{\Delta \ln(MP)}$ is the simulated price instrument using consumption levels from six months earlier. *Weather Controls* include cubic splines in growing degree days and total precipitation per billing cycle, with knots at each decile of the variables' distributions. *Past Consumption* controls of "Splines" employ a cubic spline approach for household consumption six months prior akin to weather controls, while "MY \times Pctl" indicates percentiles of consumption six months prior interacted with the month-year (2,905 fixed effects).

Table 5: Full Period Price Elasticity Estimates

	(1)	(2)	(3)	(4)	(5)	(6)
<i>Coefficients</i>						
$\Delta \widehat{\ln(AP)}$	-1.479** (0.6842)	-0.6951*** (0.2064)	-0.6979*** (0.2294)	-0.9603*** (0.1098)	-1.235*** (0.2903)	-2.2313*** (0.5724)
$\Delta \widehat{\ln(AP)} \times \text{EUP}$	0.6223 (0.6576)	2.423*** (0.2952)	2.419*** (0.5360)	0.5249*** (0.1318)	0.5584 (0.4523)	3.8184*** (0.8188)
$\Delta \widehat{\ln(AP)} \times \text{Post-EUP}$	1.733** (0.7362)	0.6527*** (0.2196)	0.6318** (0.2464)	0.8014*** (0.1196)	0.7819*** (0.2419)	1.7173*** (0.4495)
<i>Elasticities</i>						
Pre-EUP	-1.479** (0.6842)	-0.6951*** (0.2064)	-0.6979*** (0.2294)	-0.9603*** (0.1098)	-1.235*** (0.2903)	-2.2313*** (0.5724)
EUP	-0.8568*** (0.1058)	1.7281*** (0.2154)	1.7209*** (0.5406)	-0.4354*** (0.1513)	-0.6770*** (0.2863)	1.5871*** (1.096)
Post-EUP	0.2543 (0.1988)	-0.0424 (0.0595)	-0.0661 (0.0631)	-0.1588*** (0.10587)	-0.4535 (0.3682)	-0.5140 (0.4178)
Weather Splines	No	Yes	Yes	Yes	Yes	Yes
Past Consumption Controls	No	Yes	Yes	Yes	Yes	Yes
Month-Year + Zip-5 FE	No	No	Yes	No	No	Yes
Month-Year \times Zip-9 FE	No	No	No	Yes	Yes	No
Sample	Full	Full	Full	Full	Ever 1K+	EUs
Observations	8,865,514	8,806,650	8,806,650	8,806,650	1,086,296	148,598
Adjusted R ²	0.031	0.092	0.092	0.133	0.316	0.297

* p < 0.10, ** p < 0.05, *** p < 0.01. Standard errors are two-way clustered by fiscal year and 5-digit zipcode. These models report price coefficients (top panel) and combined elasticities (bottom panel) for detached single-family homes in the San Francisco East Bay Area using data from April 1, 2012 through May 31, 2019. “EUP” denotes the period of time while the Excessive Use Penalty Ordinance (EUP) was in effect from July 1, 2015 through May 3, 2016 while “Post-EUP” denotes all periods after the policy ended. The dependent variable $\Delta \ln(Q)$ measures the change in the log of gallons per day by a household between the current billing cycle and the same period in the previous year. $\Delta \widehat{\ln(AP)}$ is the simulated log annual change in prices using consumption levels from six months earlier. *Weather Splines* denote cubic splines in growing degree days and total precipitation per billing cycle, with knots at each decile of the variables’ distributions. *Past Consumption Controls* indicates percentiles of consumption six months prior interacted with the month-year (6,012 fixed effects). The “Ever 1K+” sample restricts the sample to households who ever use over 1,000 gallons per day while “EUs” only uses households that violated the Excessive Use Penalty Ordinance.

Table 6: Responses to Behavioral Policies and Comparable Price Changes

Moral Suasion						
Model	Sample	First-Year Effect	Period	Elasticity Estimate	Median AP	Necessary AP %↑
(1)	Full	-0.115***	Pre-EUP	-1.090***	\$5.05	11.2%
(2)	Full	-0.115***	EUP	-0.435***	\$7.05	30.3%
(3)	Full	-0.115***	Post-EUP	-0.159***	\$7.09	107%
(4)	Ever 1K+	-0.095***	EUP	-0.677**	\$6.73	15.1%
(5)	EUs	-0.500***	EUP	1.587*	\$6.73	NA
Public Shame						
Model	Sample	First-Year Effect	Period	Elasticity Estimate	Median AP	Necessary AP %↑
(1)	Full	-0.3033***	Pre-EUP	-1.090***	\$5.05	32.1%
(2)	Full	-0.3033***	EUP	-0.435***	\$7.05	100.7%
(3)	Full	-0.3033***	Post-EUP	-0.159***	\$7.09	574%
(4)	Ever 1K+	-0.231***	EUP	-0.677**	\$6.73	40.6%
(5)	EUs	-0.244***	EUP	1.587*	\$6.73	NA

This table uses first-year ATTs for behavioral policy instruments, price elasticities, and median average prices to calculate the average price changes necessary to have induced an equivalent conservation behavior through prices alone. All first-year ATTs and price elasticities are obtained from corresponding models reported in Figures 10-11 and Table 5, with median average prices calculated from appropriate samples. “Full” denotes estimates from Column (4) in Table 5 that utilizes the full analysis sample and includes all preferred controls. “Ever 1K+” uses observations for households that ever used over 1,000 gallons per day (Column 5) while “EUs” restrict the sample to households that violated the Excessive Use Penalty (Column 6). “Pre-EUP” elasticities utilize the coefficient on the un-interacted price instrument while “EUP” and “Post-EUP” add to it the interaction for the differences during and after the EUP, respectively. The necessary percent increases in average prices is calculated as $\% \Delta AP = \left(\frac{AP' - AP}{AP} \right) \times 100$, where $AP' = \exp(ATT/\eta + \ln AP)$ is the necessary average price to achieve the same conservation given a behavioral instrument first-year effect ATT and a price elasticity η .

A Appendix to “Culpable Consumption: Residential Response to Price and Non-Price Water Conservation Measures”



September 3, 2015

IMPORTANT INFORMATION - EXCESSIVE WATER USE ORDINANCE

Dear Customer:

RE: Account No. [REDACTED]

As you are aware, California is in a critical drought. EBMUD and the State of California have declared a critical drought emergency and adopted mandatory restrictions on outdoor water use. EBMUD also has adopted an Excessive Water Use Ordinance that prohibits single family residences from using more than 80 units per two month billing period (approximately 1,000 gallons per day). You are receiving this letter because EBMUD is reaching out to all residential water users who our records show have consistently used a high volume of water (more than 750 gallons per day) in recent months, which means the household is exceeding or could exceed the allowable limit. We want to work with you to help you conserve water. Sometimes high use is the result of unnoticed leaks and we urge you to check your water system for leaks and let us know if you find and repair a leak.

We realize some high-volume users have made substantial investments in water conserving fixtures and landscapes and if you have done that, thank you. However, water use cutbacks are required to ensure that adequate water resources remain available for all customers during this time of severe drought that potentially will continue into 2016. You may have received a letter in June advising you of EBMUD's Excessive Water Use Penalty Ordinance (no. 364-15) and encouraging you to take additional measures to conserve. Today's letter reminds you, as a customer whose recent water use has been high, that **water use above 80 units (approximately 1,000 gallons per day) during a two-month billing cycle is prohibited and has consequences.**

Financial Penalty. Excessive use will result in a financial penalty of \$2.00 for each unit in excess of the 80 unit maximum. If you receive a water bill with any applicable penalty, that bill serves as the notice of violation of EBMUD's rules and regulations.

Public Disclosure Requirements. The California Public Records Act (Government Code sections 6250-6276.48) requires EBMUD to release the name, home address and water use data of customers using water in violation of EBMUD's regulations and ordinance if that data is requested pursuant to a Public Records Act request. In the past EBMUD has received public

Figure A.1: East Bay Municipal Utility District (EBMUD) warning letter (Source: EBMUD). This figure shows a copy of the warning letter sent to high-usage households during the Excessive Use Penalty Ordinance (EUP), informing them of the consequences of violating the policy and need to conserve water.

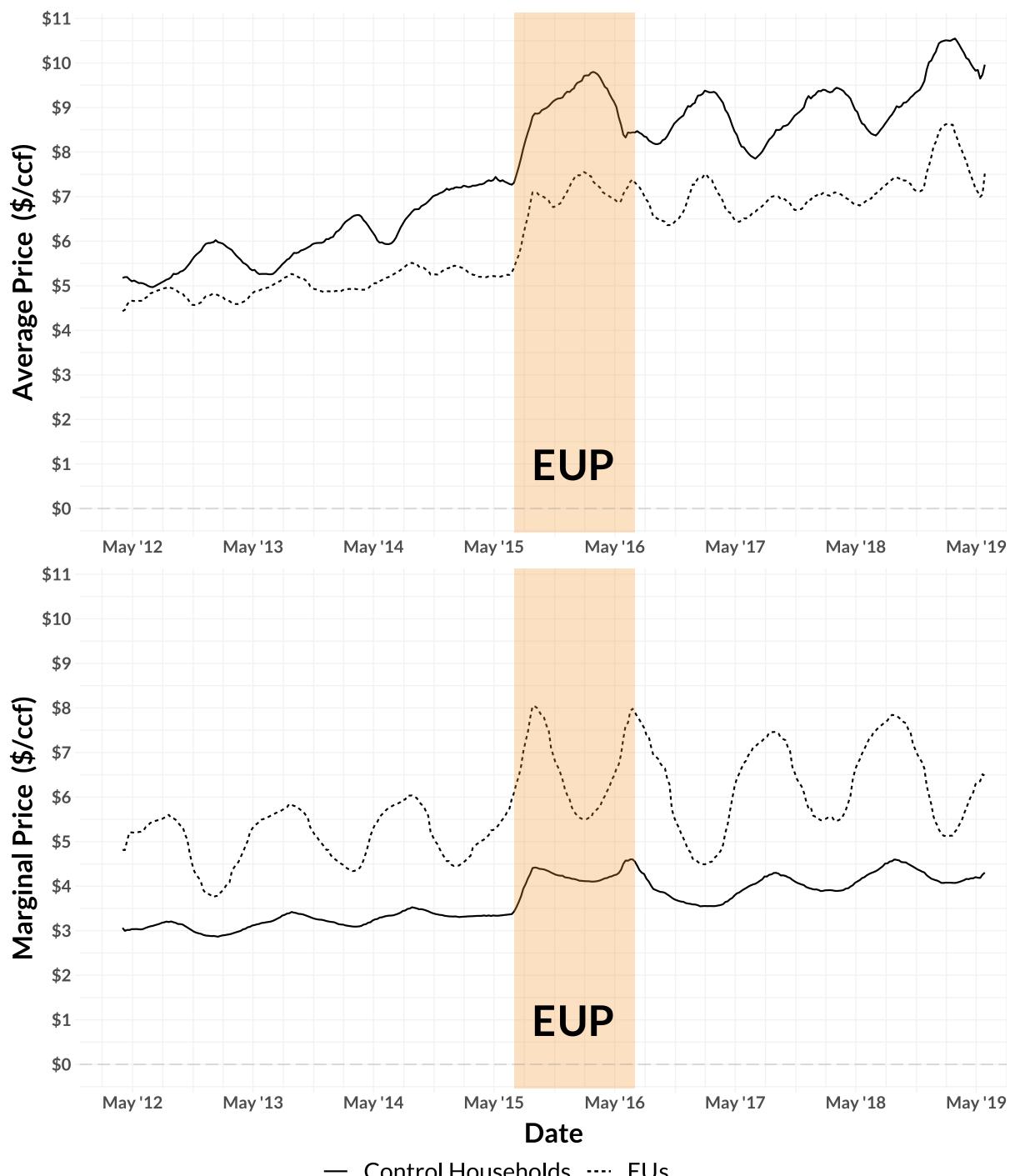


Figure A.2: Average and marginal water prices over time. This figure plots the mean average (top panel) and marginal (bottom panel) prices per one hundred cubic foot unit (CCF) of water for detached single family homes in the EBMUD service area from April 2012 through May 2019. The dotted line reports the average (marginal) prices for customers that violated the EUP while the policy was in effect (indicated by the orange band) and were exposed to fees, moral suasion, and potentially public shame (“EUs”). The solid line reports average (marginal) prices for all other single family customers that were not directly exposed to EUP policy instruments (“Control Households”).

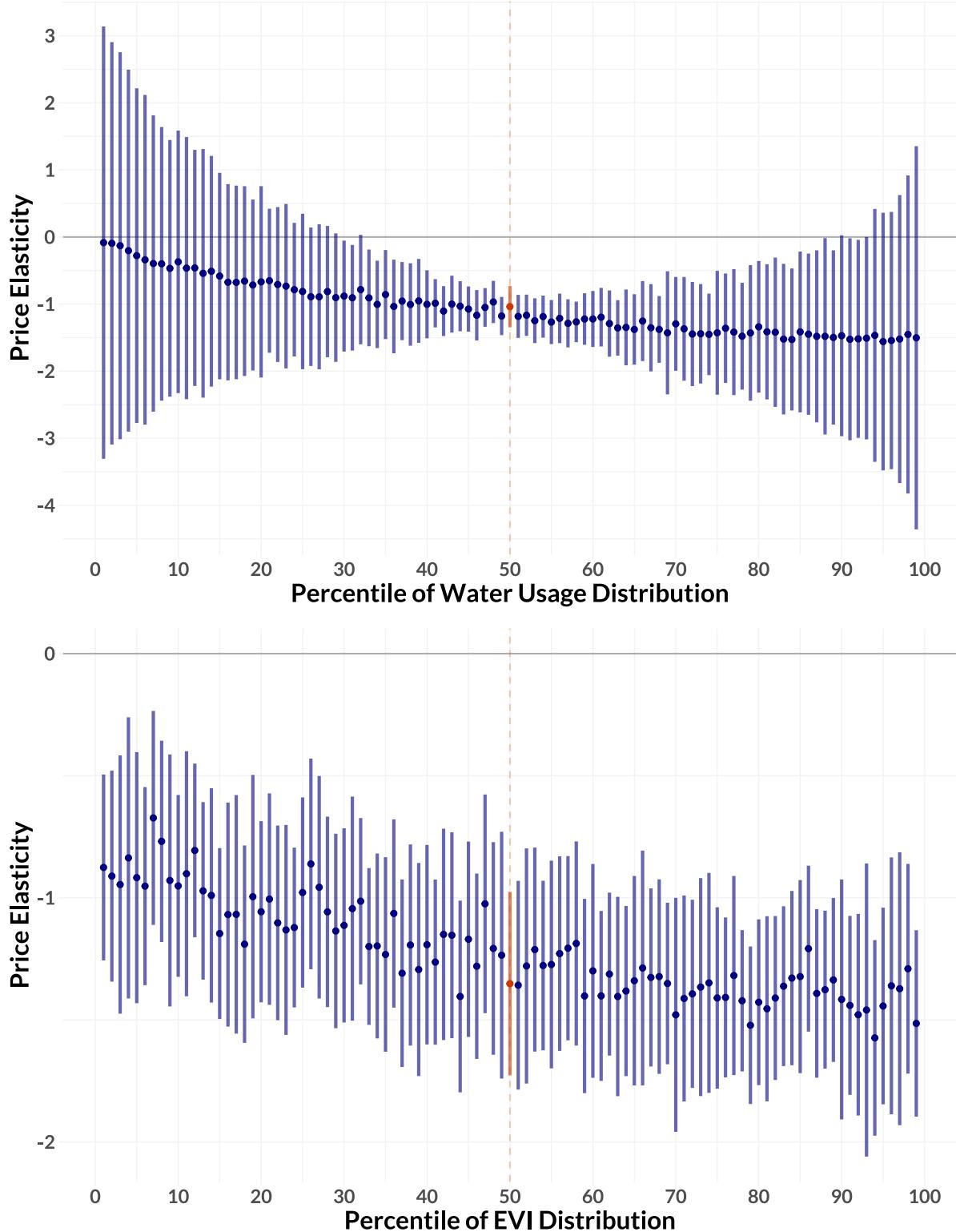


Figure A.3: Price elasticity heterogeneity by average household water usage. This figure plots the coefficients and 95% confidence intervals for the overall price elasticity at each percentile of average household water consumption in the top panel and average parcel vegetation (EVI) in the bottom panel. Estimates are obtained using models that follow Eq. 1 where the price instrument is interacted with each percentile of a given variable's distribution. Each point estimate is calculated as the sum of the percentile's interaction term and the coefficient on the baseline term (50th specified as the omitted group) with the standard error of the sum calculated from the relevant components of the variance-covariance matrix.

Table A.1: Residential Water Price Schedules over Time

Fiscal Year	Service Charge	Marginal Prices			Elevation Surcharges	
		Tier 1	Tier 2	Tier 3	Band 2	Band 3
2012	\$25.24	\$2.28	\$2.83	\$3.47	\$0.43	\$0.88
2013	\$26.74	\$2.42	\$3.00	\$3.68	\$0.46	\$0.93
2014	\$29.34	\$2.66	\$3.29	\$4.04	\$0.50	\$1.02
2015	\$32.12	\$2.91	\$3.60	\$4.42	\$0.55	\$1.12
2016	\$38.68	\$2.95	\$4.06	\$5.36	\$0.60	\$1.24
2017	\$41.38	\$3.16	\$4.34	\$5.74	\$0.64	\$1.33
2018	\$45.20	\$3.45	\$4.74	\$6.27	\$0.70	\$1.45
2019	\$49.26	\$3.76	\$5.17	\$6.83	\$0.76	\$1.56

This table reports marginal prices and elevation surcharges within the EBMUD service area for Fiscal Years 2012-2019. “Marginal Prices” represent the cost of consuming a volume of water equal to one hundred cubic feet of water (or CCF, equal to 748 gallons) for units consumed within consumption tier 1 (0-14 CCF), tier 2 (15-32 CCF), and tier 3 (33+ CCF). “Elevation Surcharges” report the surcharge paid for every CCF used by homes in elevation band 2 (approximately 200-600 feet) and band 3 ($\approx 600+$ feet).

Table A.2: Drought Surcharges, Fiscal Year 2016

Drought Stage	Consumption Tier		
	Tier 1	Tier 2	Tier 3
0 (Normal)	\$0	\$0	\$0
1 (Moderate)	\$0	\$0	\$0
2 (Significant)	\$0.23	\$0.31	\$0.40
3 (Severe)	\$0.59	\$0.79	\$1.03
4 (Critical)	\$0.73	\$0.99	\$1.3

This table reports EBMUD drought surcharges for fiscal year 2016. While the drought surcharges were in effect, marginal prices for units consumed in a given tier increased by the listed amount.

Table A.3: EBMUD Elevation Bands

Band	Description	Surcharge	% Sample
1	Homes in pressure zones that do not require pumping (approximately 0-200 feet above sea level)	None	56.24%
2	Homes in pressure zones requiring pumping (approximately 200-600 feet above sea level)	12-20% MP	35.54%
3	Homes in pressure zones requiring “considerable” pumping (approximately 600+ feet above sea level)	23-42% MP	9.21%

This table reports information and approximate cutoff elevations for the EBMUD service area elevation bands. Elevation thresholds are approximate as elevation band assignment is ultimately determined by pressure zone membership, which is influenced by elevation as well as water pressure and pumping requirements. Surcharges are reported as the percent of marginal prices faced across all consumption tiers.

Table A.4: Comparison Across Elevation Band Cutoffs, Alameda County

	Band 2 (200-600ft)		P-Val	Band 3 (> 600ft)		P-Val
	Below (190-199ft)	Above (201-210ft)		Below (590-599ft)	Above (601-610ft)	
Mean Temp (°C)	14.900 (2.976)	14.909 (2.952)	0.03	14.556 (3.279)	14.531 (3.260)	0.48
Total Precip. (mm)	95.593 (116.816)	96.254 (117.418)	0.16	104.306 (126.020)	103.635 (125.283)	0.02
Home Size (sqft)	1,569 (560)	1,617 (580)	0.00	2,437 (892)	2,374 (817)	0.00
Lot Size (sqft)	5,643 (2,604)	6,393 (48,267)	0.00	11,523 (13,050)	14,030 (34,873)	0.00
# Bedrooms	2.962 (0.955)	2.987 (0.924)	0.00	3.423 (1.149)	3.420 (1.089)	0.91
# Bathrooms	1.725 (0.755)	1.794 (0.810)	0.00	2.503 (0.946)	2.491 (0.913)	0.26
Owner-Occupied	0.632 (0.227)	0.659 (0.225)	0.00	0.891 (0.097)	0.899 (0.103)	0.00
HH Income >\$200K	0.125 (0.136)	0.129 (0.132)	0.00	0.302 (0.142)	0.341 (0.189)	0.50
Observations	153,973	180,685		73,037	63,456	

This table reports summary statistics for homes in Alameda County just on either side of the EBMUD service area elevation band cutoffs. “Below” (“Above”) columns report the means for homes within 10 feet of elevation below (above) the approximate cutoffs for elevation bands 2 and 3. “P-Val” reports the p-value for the test of equality of means above and below each boundary.