Determinants of Water Conservation: Evidence from a California Drought [*]

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June 14, 2019

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Abstract

This paper uses hourly micro-data from 82,300 single-family household to evaluate residential water conservation policies adopted during drought by a large Californian water utility. Specifically, we disentangle the impacts of rate changes, outdoor watering restrictions, and public-awareness policies, as well as enforcement and rebate programs. We find several key results. First, the price elasticity of demand for water is estimated to be 22% for marginal rates and 41% for average rates. Second, reducing the number of days households are allowed to use water outdoors results in a substitution of water use from banned days to the remaining non-banned days. Third, drought awareness increases after key State-wide drought-related announcements. However, this increased awareness does not contribute substantially to realized water savings. Finally, adoption of rebates for water-efficient toilets and lawn replacement appears to lead to substantial water savings, as does adoption of free timer tutorials and water use audits.

1 Introduction

It is vital for utilities to understand which policies effectively induce water conservation, especially as climate change is expected to increase the frequency and severity of droughts in arid regions worldwide. Moreover, these droughts will likely be exacerbated by growing populations and increased costs of developing new supply. Between 2011 and 2017, California experienced an unprecedented drought, by some measures the worst in over 1,200 years (Griffin and Anchukaitis, 2014). As shown in Figure 1, the United States Department of Agriculture measured a record 78% of the state to be in either 'Extreme' or 'Exceptional' drought. In an attempt to reduce residential water consumption, utilities deployed a range of policies: they introduced or tightened outdoor water use restrictions, raised water rates, funded public awareness campaigns, and increased rebates on water-efficient appliances. California Governor Jerry Brown declared a State of Emergency in January 2014, which culminated in an April 2015 mandate that utilities reduce water use by 25% relative to a 2013 baseline. The policy was a surprising success, 43% of Californian utilities achieved their State-mandated conservation goal. However, it is unclear which specific policy levers resulted in the most water conservation.

This paper seeks to answer this question by disentangling the effect different state and municipal policies had on residential water use in the 2011-2017 California drought. We use hourly water use data from over 82,300 single-family households in a large Californian city between 2013 and 2016. Fresno, California is one of a few large cities that has universally adopted advanced metering infrastructure, that is 'smart meters' which communicate continuously with the utility. Hourly data from these meters allow us to estimate the differential impacts of policies across different hours of the day, which is crucial to study compliance with regulations that schedule when outdoor water use is permitted. Figure 2 shows that water use in 2013 in

Fresno was comparable to California as a whole, suggesting that it can offer a useful case study to learn about water conservation policies elsewhere.

During our sample period, Fresno implemented a suite of water conservation policies, including six rate changes and a reduction in the number of days that households could use water outdoors. Our sample period also covers two state-level regulatory announcements related to the drought: the State of Emergency declaration in January 2014, and the April 2015 mandate requiring all utilities to reduce water use by 25% relative to a 2013 baseline. Throughout our sample period, the City also continued to offer rebates and free customer services to encourage water conservation. Figure 3 summarizes the policies we study alongside the aggregate patterns in weekly average water use we observe in our sample. Water use is highly seasonal, peaking in summer as outdoor irrigation increases. From 2013 to 2015 water use decreases year on year, a trend that stops in 2016 as the drought eased. Figure 3 underscores the simultaneity of the policies implemented to reduce water use, and thus the challenge we face in disentangling their individual impacts. Our empirical analysis controls for seasonality using week-of-year fixed-effects and weather controls. Our preferred specification does not include year fixed effects because given our relatively short time frame, the fixed effects would absorb important variation in outcomes necessary to identify the effects of the policies of interest.

We present four main findings. First, we find a 20% elasticity with respect to marginal price and a 44% elasticity with respect to average price. Rate changes account for 33% of the policy-induced water savings in our city between the first semester of 2013 and the year 2016.

Second, we study a change in the outdoor water schedule regulations that reduced the number of days outdoor water use was permitted. Our analysis shows that after this policy, households substitute water use from banned to permitted days. Nonetheless, water use persistently decreases by between 21% and 24%, contributing to around 65% of the policy-induced water savings in our city between the first semester of 2013 and the year 2016. Importantly, water use decreases also during hours when outdoor use was not permitted even prior to the schedule change. This suggests that households might have reacted to the announcement of the schedule change, rather than the schedule change itself.

Third, we observe that after the "State of Emergency" and "Mandated Reductions" announcements, interest in the California drought increases, as measured by a Google search index for the keyword "drought". However, this increased awareness does not appear to have contributed substantially to the realized water savings in Fresno during our sample period.

Fourth, households who install water-efficient toilets and drought-resistant lawns through a rebate program experience reductions in water use of 8% and 7% respectively. By contrast, we find some evidence that take-up of water-efficient washer rebates leads to rebound effects on water use. Similarly, we find that customer service visits offering free timer tutorials and water use audits reduce household water use by 4% and 19% respectively. However, due to low take-up rates, the aggregate impacts of these rebates and customer services are negligible.

We make two main contributions to the literature comparing the effectiveness of price and non-price approaches to urban water conservation (Olmstead and Stavins, 2009). First, we use a four-year panel of high-frequency water use data to estimate the effects of several rate changes as well as non-price policies, including awareness campaigns and command-and-control programs. Second, we exploit our rich hourly data to investigate how water use patterns throughout the day change with changes in command-and-control policies.

Our findings that both price and non-price instruments can reduce water use are consistent with results by Pratt (2019), West et al. (2018), and Wichman, Taylor, and Haefen (2016). Our finding that rate changes have a significant impact on water consumption is consistent with the existing literature which estimates the short-run price elasticity of residential demand for water to be plausibly between -0.3 and -0.5, with more extreme estimates of -0.12 to -1.14 (Baerenklau, Schwabe, and Dinar, 2014; Wichman, 2014; Klaiber et al., 2014; Ito, 2013; Mansur and Olmstead, 2012; Nataraj and Hanemann, 2011; Halich and Stephenson, 2009; Olmstead, 2009; Olmstead, Hanemann, and Stavins, 2007). Importantly, these studies find heterogeneity in water demand elasticity both across households and across seasons (Wichman, 2014; Klaiber et al., 2014). Moreover, we find that customers are more sensitive to average rather than marginal prices, consistent with both the electricity and water demand literature (Ito, 2014; Wichman, 2014). By contrast, our findings on the overall small effect of drought awareness on water savings caution the previous literature on social norms and water use that shows, for example, that peer comparisons and injunctive messaging effectively reduce water use (Ferraro, Miranda, and Price, 2011; Ferraro and Price, 2013; Brent, Cook, and Olsen, 2015; Bhanot, 2018; Jessoe et al., 2018).

Several scholars have studied outdoor water use restrictions and their enforcement. Most studies find that mandated restrictions are more effective at reducing water use than voluntary restrictions, decreasing use by as much as 29 percent depending on the information content and enforcement strength (Pratt, 2019; Wichman, Taylor, and Haefen, 2016; Halich and Stephenson, 2009; Kenney, Klein, and Clark, 2004; Renwick and Green, 2000; Michelsen, McGuckin, and Stumpf, 1999). However these polices also likely reduce welfare (Grafton and Ward, 2008; Mansur and Olmstead, 2012). Importantly, the possibility to substitute water use across days and times within a week mitigates both the effectiveness of the policy and also the associated disutility (Hensher, Shore, and Train, 2006). Indeed, Castledine et al. (2014) use daily water consumption data to show that flexible implementation of outdoor watering restrictions can be more effective at inducing water conservation than a more inflexible approach, but allowing watering on more days per week translates into higher weekly use. Using hourly water use data, we are the first to estimate not only the day-of-week effect, but also the time-of-day effect that these restrictions on outdoor water use have on household behavior. Specifically, we confirm that households substitute water use between days in a week to compensate for the schedule change that allows for one less watering day; moreover, households substitute water use towards permitted hours on permitted days, partially offsetting the reductions achieved during banned hours. We are also able to show that enforcement actions do not have long terms effects on individual use because of the way enforcement is targeted to customers with large increases in use, a mechanism that can likely explain similar findings by Zhang and Teodoro (2018).

Finally, we contribute to a growing literature studying water-efficient appliances. For example, Jessoe et al. (2018) show that peer comparisons increase take-up of water efficient appliances, while Bollinger, Burkhardt, and Gillingham (2018) show that households subject to high water fees imitate their neighbors who switch to dry vegetation. However, Bennear, J. M. Lee, and Taylor (2013), M. Lee, Tansel, and Balbin (2011), and M. Lee, Tansel, and Balbin (2013) show a rebound effect on water use after adoption of these appliances. After installation, consumers respond to a perceived lack of effectiveness of high-efficiency devices by using them for longer or more frequently, dampening the conservation benefits. Similarly, L. W. Davis (2008) examines changes in behavior associated with installation of high-efficiency clothes washers and finds a small rebound effect, suggesting that the average household increases their utilization of clothes washing machines. We complement this literature by showing that, while adoption of water-efficient clothes washer rebates does not reduce household water use, low-flow toilet adoption does reduce water use. This result suggests that rebound effects play a smaller role in toilet use than in washer use.

The paper proceeds as follows: Section 2 describes the data. Section 3 examines the impact of each city-wide policy adopted in Fresno on patterns of water use individually. Section 4 discusses additional policy levers cities can use, such a rebates, enforcement actions, and customer service. Section 5 estimates the impact of conservation policies simultaneously and discusses the extent to which each policy explains the observed changes in water use during our sample period. Section 6 concludes.

2 Data

We observe hourly water use between 2013 and 2016 for the universe of single-family households in Fresno, one of the five largest cities in California. In cleaning the data we drop all newly constructed houses, abandoned houses and households with a change of address during our sample period. We also drop all hours when smart-meter transmission malfunctions lead to implausible estimates of water use more than 4 standard deviations away from the city's average. This process leaves us with around 31,400 hourly observations for over 82,300 households.

Appendix Table A.I compares demographic and climate characteristics, as well as average water use in Fresno, our sample city with the top 100 municipalities in California. Appendix Figure A.1 maps the average maximum temperature and rainfall across all of California. Fresno is quite populous, albeit poorer than the rest of urban California. It ranked in the middle third among the top 100 municipalities for baseline water use, and it registers rainfall and high temperatures that are close to the median for the state, although its daily low temperatures are among the highest. In general, Fresno offers a reasonable case study for other cities in California and the US South.

3 Policies Driving Water Conservation

This section discusses the impact of each city-wide conservation policy implemented in Fresno on household water use separately. Specifically, we study the impact of: 1) rate changes, 2) a reduction in the number of outdoor watering days, and 3) state-wide regulatory announcements. In section 5, we pool all of these policies together to estimate their simultaneous impact.

To evaluate each policy, we employ different empirical approaches depending on the identifying variation generated by its implementation. In general, we use an event-time framework, controlling for week-of-year fixed-effects to partial out seasonal variation. In this framework, the treatment effect is identified by the change in water use relative to the average water use in a given week in the other three years of the sample. Our use of week-of-year fixed effects is likely conservative: part of the impact of any policy change will be absorbed by these fixed effects given the small number of years in our sample. When additional variation is available, we compare households differentially impacted by a given policy in a difference-in-differences design to partial out cross-sectional variation. In this design, the treatment effect is identified by the change in water use between a household who is affected by a treatment at a given time (such as the prohibition to use water outdoor) and another household who is not. For all our regression estimates, we cluster our standard errors at the household and sample month level to account for serial correlation and city-level shocks.

3.1 Rate changes

This section estimates the impact of rate changes on household water use. Appendix Figure A.4 shows the time-line and magnitude of six different rate changes in our sample for marginal, fixed, and average rates separately. Between the beginning and end of this period, marginal rates increased in Fresno. Yet, some rate changes reduced both marginal and fixed rates: notably, in August 2014 the City reversed previous rate increases under political pressure from ratepayers, only to increase rates again the next year after approving a new rate-setting process. This episode emphasizes the degree to which rate changes were salient to households during our sample period.

Because rate changes hit all households in the city simultaneously, our estimates are identified off of time series variation. Specifically, we compare water use within the same week across different years when different rates are in place. We estimate the following equation:

$$y_{it} = \text{IHS}(\text{Rates})_{it} + \gamma_{woy} + \gamma_i + X_t\theta + \varepsilon_{it} \tag{1}$$

where y_{it} is the inverse hyperbolic sine of household's i average daily water use in gallons and $\text{IHS}(\text{Rates})_{ct}$ is the inverse hyperbolic sine of the marginal, fixed, or average water rate at day t, depending on the specification. We use the inverse hyperbolic sine to estimate elastities rather than the logarithm because of its robustness to the inclusion of observations with zero water use, which make up a significant fraction of our hourly dataset. [1] γ_{woy} and γ_i are week-of-year, and household fixed effects, X_t are weather and seasonal controls. Our preferred specification does not include year fixed effects because they would absorb any persistent effects of the policies we study.

Table I presents our estimates. Columns 1 and 2, which include year fixed effects, appear to suggest customers are not very sensitive to prices when comparing within-year water use. By contrast, Columns 3 and 4, which do not include year fixed effects, estimate an elasticity of 44% with respect to average prices and 20% with respect to marginal prices.[2] Columns 5 through 8, which specify the outcome variable as the log of average daily water use plus one, rather than the inverse hyperbolic sine, find similar results to Columns 1 through 4. These estimates do not take into account the fact that the city and the state both introduced other policies throughout our sample period; we account for these other factors in our price elasticity estimates in Section 5.

These estimates are consistent with the literature documenting that customers respond more strongly to average rather than marginal electricity prices. Specifically, Ito (2013) finds that California customers display a short-run elasticity to average price of 9.7% to 12.7%. It is important to note, however, that Fresno does not have increasing block rates, thus we cannot use any identifying variation across customers other than their baseline water use. Related, we estimate a large and positive coefficient for the effect of fixed rates on water use; however, because we have no cross-sectional variation in fixed rates we do not believe our estimation strategy correctly identifies the effects of fixed rates.

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[1] We multiply in argument of the inverse hyperbolic sine transformations by a large number, 100,000,000, to include observations where the arguments are 0. Algebraically, the multiplicative constant does not affect the regression estimates. Our results are also robust to using the logarithm of one plus dependent and independent variables in our regressions.

[2] We follow Bellemare and Wichman, forthcoming to compute elasticities.

3.2 Reducing the number of allowed outdoor watering days

Next, we evaluate non-price policies, starting with time-of-day and day-of-week restrictions on outdoor water use. These restrictions are ubiquitous throughout California and other drought-prone states and typically target lawn irrigation, which represents the single largest end-use of residential water (Hanak and M. Davis, 2006). 70% of Californians were already subject to some restrictions on outdoor water use, even before drought regulations made them mandatory.[3] Typically these policies restrict outdoor water use to only nights and evenings, when less water is lost to evaporation, and also limit the number of days in a week households can use water outdoors. During our sample period, outdoor water use violations in Fresno were subject to a $45 fine. A small team of utility representatives patrolled the city, often at night, targeting customers with a history of high water use during banned hours and issuing fines to customers caught violating water use regulations. First-time violators had the option of having the fine waived if they agreed to a household water audit.

It is not clear whether tightening these regulations will reduce aggregate water use. On the one hand, advocates argue that these regulations nudge households to irrigate their lawns at times when lawns can absorb the most water and prevent over-irrigation. On the other hand, these regulations do not limit total water use, as households can substitute between hours or days. This section answers this question by exploiting a watering schedule change in August 2014, which reduced the number of permitted watering days during summer months from three days to two days a week. Appendix Table A.II summarizes the summer watering schedule before and after this change. To reduce the load on the storm water system, odd and even numbered houses are allowed to use water outdoors on different days of the week. During summers prior to August 2014, even-numbered houses were permitted to use water outdoors on Wednesdays, Fridays, and Sundays while odd-numbered houses were permitted to use water outdoors on Tuesdays, Thursdays, and Saturdays. Beginning August 2014, all customers were also prohibited from using water outdoors on Thursdays and Fridays. On Mondays, all households in Fresno are banned from using water outdoors.

We exploit the fact that even- and odd-numbered households are allowed to water outdoors on different days of the week to estimate the net effect of the schedule restriction. For example, we can compare the behavior of two neighbors living on the opposite side of the street, at numbers 1 and 2, on different days of the week. Household 1 was never allowed to water on Fridays and can serve as a control group for Household 2, who is prohibited from watering on Fridays starting in August 2014, and vice-versa on Thursdays. If we assume that all households comply with the watering schedule, then the difference between even-numbered and odd-numbered household water use on different days would be entirely accounted for by outdoor water

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[3] Authors' calculation based on State Water Resource Control Board data on Conservation Reporting.

use. To the extent that some households do not comply with this regulation, by using differences in water use of households with different watering schedules, we likely underestimate true outdoor water use and consequent savings from this policy restriction.

Figure 4 illustrates our natural experiment by plotting the difference in water use between even- and odd-numbered households on Wednesdays and Fridays from 2013 to 2016, normalized by month and day of week to take out seasonal trends. Prior to August 2014, even-numbered houses were permitted to use water outdoors on both of these days while odd-numbered homes were not, thus the difference between even and odd water use on these days is very similar. After the ban of outdoor water use on Fridays for even-numbered households in August 2014, the difference in water use on Fridays between even- and odd-numbered households falls as even-numbered houses stop using water on Fridays. Simultaneously, we see a substantial increase in water use for even-numbered households on Wednesdays as they substitute to using more water on still-permitted days of the week. This substitution pattern suggests that households' behavioral responses reduce the effectiveness of the policy with respect to naive mechanical effects. The highly seasonal response to this policy change is consistent with the fact that most irrigation occurs during summer months, whilst almost no irrigation takes place during the winter.

In the spirit of Figure 4, we exploit our unique hourly data to further unpack the impact that tightening these outdoor watering restrictions had on water use on different days and at different times, in a difference-in-differences design. Specifically, we estimate the following equation for each hour of the day on the sample of summer months, when outdoor water restrictions are in place:[4]

$$\begin{aligned}y_{it} =& \beta_1 \text{BannedDay}_i + \beta_2 \text{AlwaysPermitted}_i \\ &+ \beta_3 \text{PostBan}_t + \beta_4 \text{BannedDay}_i \times \text{PostBan}_t + \beta_5 \text{AlwaysPermitted}_i \times \text{PostBan}_t \\ &+ \gamma_i + \gamma_{dow} + \gamma_{woy} + \gamma_{yr} + \varepsilon_{it} \qquad (2)\end{aligned}$$

where BannedDay_i is an indicator for the days that become banned in August 2014, that is Thursdays for odd-numbered homes and Fridays for even-numbered homes. AlwaysPermitted_i is an indicator for days when outdoor watering is allowed both before and after August 2014.[5] The omitted category includes days when outdoor watering is not permitted either before or after August 2014.[6] PostBan_t equals one for days after the change in the outdoor watering schedule. Thus, the coefficient β_3 estimates the impact of the ban on water use, y_{it} during days when outdoor use was never permitted. The sum of $\beta_3 + \beta_4$ and $\beta_3 + \beta_5$ estimates

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[4] Due to limitations of computation power, we estimate this equation at the block group - odd/even level, weighting by number of households per block group.

[5] These days are Tuesdays and Saturdays for odd-numbered homes and Wednesdays and Sundays for even-numbered homes.

[6] These days are Mondays, Wednesdays, Fridays, and Sundays for odd-numbered homes and Mondays, Tuesdays, Thursdays, and Saturdays for even-numbered homes. See Table A.II.

the effect of the ban on water use on days that become banned and are always permitted, respectively. We control for individual fixed effects as well as fixed effects for the day of week, week-of-year and year. As such, coefficients in these regressions are identified by the comparison between an even-numbered house that is permitted to water outdoors and an odd-number house in the same Census block group that is not, and vice-versa.

Figure 5 presents the hour-by-hour estimates of these regressions on banned, always-permitted, and never-permitted days, respectively. The vertical red lines in the figure delimit daytime hours (9 am to 7 pm) when outdoor use is never permitted. The first panel shows that on the day that becomes banned, water use decreases across all hours of the day by a total of 256 gallons, with 87% of this decrease (223 gal) occurring at night during hours when irrigation became banned. However, the second panel shows that households offset these reductions by substituting 94 gallons per week of irrigation from the night that is now banned to the two nights that remain permitted. For every gallon reduction in water use on a banned day, 37% of these savings are offset by increases in water use at nights that remain permitted. Finally, all panels show a puzzling reduction in day-time water use. This reduction could reflect higher compliance with the watering schedule or increased conservation along other dimensions associated with publicity about the schedule change. Across all days of the week, these savings add up to 333 gallons per week.

Summing up, Figure 6 shows that despite the substitution of water use from newly banned to permitted times, net water use decreases virtually during all hours. Consistently, Figure 7 shows that total water use persistently decreases after the schedule change by plotting coefficients from a regression including leads and lags of the policy change. This net decrease in water use is suggestive of increased compliance with outdoor use regulations after the schedule change. One potential explanation is that the change in the schedule increased overall awareness of the drought or its severity which might have lead to a general decrease in water use (Pratt, 2019). Section 3.3 investigates this channel further. Alternative explanations include households changing lawns and gardens in a way that requires less watering across the board in response to the schedule change, although Appendix Figure A.2 does not show any discontinuous increase in take-up of lawn replacement rebates. In addition, Section 4.1 explores the potential role of enforcement of these regulations and provision of free water conservation services in reducing water use. For example, Appendix Figure A.3 shows that in August 2014, together with tightening outdoor water use restrictions, the city also performed an unusual number of timer tutorials. By contrast, we do not observe increases in the number of audits performed around the schedule change.

3.3 Increasing Public Awareness

Many environmental programs appeal to moral values to induce behavioral change; yet, it is not clear that they are effective (Egebark and Ekström, 2016). This section examines the extent to which two key policies enacted by the State of California affected public awareness of the drought using Google Trends data: the State of Emergency declaration and the introduction of mandatory water use reductions. We then investigate whether the increased drought awareness during our sample period also led to changes in water use.

First, on January 17, 2014, Governor Jerry Brown declared the whole of California to be in a State of Emergency as a result of the drought. This declaration allowed the state to access federal disaster relief funds and gave the state additional jurisdiction over local water institutions to manage water supply. The governor lifted the State of Emergency after the end our sample period, on April 7, 2017 for most of the State, although some counties remained under it for longer. Second, on April 1, 2015 the State imposed unprecedented mandatory water use reductions on all local water utilities. Requirements included reporting water use monthly to the state as well as 25% reductions in water use relative to 2013.[7]

Because these policies were one-time announcements which affected all households simultaneously, we exploit time series variation by estimating a regression of water use on a sequence of event-time dummy variables whilst controlling for secular trends, seasonality, as well as individual fixed effects. In other words, we estimate the following equation:

$$y_{it} = \sum_{s=-13}^{13} \beta_s I_t^{\text{Weeks Post-Announcement}} + \gamma_{woy} + \gamma_{yr} + \gamma_i + X_t\theta + \varepsilon_{it} \tag{3}$$

where $I_t^{\text{Weeks Post-Announcement}}$ is an indicator for week t being s weeks before or after the announcement.[8] γ_i, γ_{yr}, and γ_{woy} are household, year, and week-of-year fixed effects, and X_t are weather controls.

First, we examine the effect of these policies on drought awareness. We use Google Trends to construct a weekly index of the number of searches within Fresno containing the word "Drought". Figure 8 plots the coefficients from equation (3) where y_{at} is the drought awareness index.[9] Both policy announcements, and especially the State of Emergency announcement, appear to increase awareness of the drought as measured by our index. By contrast, the change in the outdoor watering schedule does not appear to increase drought awareness.

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[7] In addition, this regulation instituted a temporary, state-wide consumer rebate program to replace old appliances with water- and energy-efficient models; required campuses, golf courses, cemeteries, and other properties with large green spaces to make significant cuts in water use; prohibited new home developments from irrigating with potable water; prohibited irrigation of street medians; prohibited the serving of tap water in restaurants unless asked for by customers; and prohibited irrigation in days following rainfall.

[8] Indicators for weeks -13 and 13 include also weeks before and after the window, respectively.

[9] Because the drought awareness index is constructed at the city level, this specification does not include household fixed effects.

Next, we ask whether this increase in awareness translates in decreases in water use. Appendix Figure A.5 plots this measure of drought interest against water use after removing seasonal patterns. Average water use and interest in the drought move in opposite directions, with a correlation coefficient of -0.5. Figure 9 further confirms this pattern by plotting the coefficients from equation (3) where y_{it} is the inverse hyperbolic sine of average daily households' water use. This figure suggests that both announcements are associated with declines in water use. We interpret these results as indicating that drought awareness might have a significant impact on water use and explore the robustness of this finding to controlling for simultaneous policies in Section 5 below.

4 Additional Policy Levers Available to Local Governments

Most water utilities in California offer rebates for water-efficient appliances on top of rebates offered by the State. Similarly, virtually all utilities in California have outdoor water use restrictions on the books, although the enforcement level varies greatly.[10] This section explores the impact of enforcement, customer services, and rebates for water-efficient appliances on households' water use. Importantly, Fresno did not amend these policies during our sample period. Therefore, we employ an event-study framework that identifies the effect of receiving a rebate, service, or an enforcement action off of the timing with which different households receive treatments, controlling for individual unobservable characteristics that lead households to take up different treatments. Moreover, because these policies existed throughout the entire duration of our sample period, the results do not identify the impact of introducing these or similar policies.

4.1 Enforcement of Outdoor Water Use Restrictions and Free Timer Tutorials

Section 3.2 above finds that general compliance with the outdoor watering schedule increased after the city decreased the number of permitted watering days from three to two. Potential explanations include increased or more effective enforcement. Indeed, State Water Resource Control Board data on Conservation Reporting show that Fresno is among the top Californian cities for enforcement actions assessed for violations of outdoor watering regulations, while 50% of utilities never assess a penalty for these violations. In this section, we investigate how water use changes when the utility fines customers for violating the outdoor watering schedule. First-time violators have the option of having the fine waived if they agree to a household water audit. During these audits, city representatives help households reset the timers on their automated lawn sprinklers systems in compliance with the watering schedule; in this section we also examine the impact of audits and timer tutorials on water use.

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[10] Source: State Water Resource Control Board data on Conservation Reporting.

Specifically, we estimate the following event-study equation:

$$y_{it} = \sum_{s=-13}^{13} \beta_s I_{it}^{\text{Weeks Post-Fine}} + \gamma_{woy} + \gamma_{yr} + \gamma_i + X_t\theta + \varepsilon_{it} \tag{4}$$

where $I_{it}^{\text{Weeks Post-Fine}}$ is an indicator for week t being s weeks before or after customer i received a fine, audit, or tutorial. γ_i, γ_{yr}, and γ_{woy} are household, year, and week-of-year fixed effects, and X_t are weather controls. Figures 10 and 11 plot coefficients from this regression, while Table II reports coefficients on the simple indicators for days after fine, audit, or tutorial.

Figures 10 and 11 show a sharp upward trend in water use before the receipt of a fine, an audit, or timer tutorial. This upward pre-trend could reflect either changes in water use behavior leading up to the households receiving fines or audits, or alternatively the potential development of leaks. This pre-trend is also consistent with the city's enforcement protocol that targets high water users for visual inspections, which in turn might result in fines or customer services. Consequently, when we estimate the long-term impacts of receiving fines, audits, and timer tutorials, the estimates are attenuated relative to the short-term, since these policies largely correct deviations in short-term behavior. Consistently, Figure 10 shows over a 40% decline in water use within two weeks of a fine. However, Table II shows that after a fine there is no significant long-term reduction in water use. By contrast, timer tutorials and audits lead to 4% and 19% reductions in water use in the long-term; however the estimated effect of tutorials is imprecise. The more persistent long-term impact of audits relative to fines suggests that some violations might be due to customer inattention and persistent habits, rather than preferences, which can be corrected with education and customer service.

It is important to note that while seemingly effective in correcting increasing trends in water use for individuals, enforcement strategies based on city inspectors, as well as customer service outreach are limited in scope by the City's resources. In our sample period, Fresno only issued around 13,800 fines and conducted 4,466 timer resets and 5,131 audits.

4.2 Water-efficient Appliance Rebates

Starting in 2006, Fresno offered rebates to incentivise households to install water-efficient appliances. The program offers residential households up to a $100 rebate per water-efficient washers and toilets.[11] In 2015, the City also introduced an up to $2 rebate per square foot for lawn replacement.[12] Appendix Figure A.2

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[11] The city also offers rebates for a variety of other products, however, take-up of these rebates is too low to allow a statistical analysis. These rebates include rain sensors, sprinkler nozzles, pool covers, moisture sensors recirculating hot water pumps, micro-irrigation conversion, and evaporative coolers. The city has a commercial and industrial rebate, too.

[12] Up to 2,000 dollars per household.

shows rebate take-up during our study: between 2013 and 2016, we observe 1,872 clothes washer rebates, 501 toilet rebates, and 191 turf replacements.

On top of these rebates, customers are also eligible for rebates through California's state-wide 'Save Our Water' program. The Save Our Water rebates are worth up to \$100 per water-efficient toilet and up to \$2 per square foot for lawn replacement. Anecdotally, most households redeem both rebates as they receive the forms for both rebates simultaneously, either from the vendor or from the installing contractor. Entry-level water-efficient toilets cost between \$100 and \$300, so taken together these rebates could cover the entire cost of a toilet. However, the customer would pay for installation, which in Fresno costs at least \$250. By contrast, washers' sticker prices are higher than the rebate, ranging between \$500 and \$1,000, but washers can often be installed without a plumber. Finally, the cost of lawn replacement is highly heterogeneous depending on topography and the nature of the landscape that replaces the lawn.

To estimate the impact of installation of water-efficient appliances or lawn replacements on water use we estimate the following event-study equation:

$$y_{it} = \sum_{s=-13}^{13} \beta_s I_{it}^{\text{Weeks Post-Rebate}} + \gamma_{woy} + \gamma_{yr} + \gamma_i + X_t\theta + \varepsilon_{it} \tag{5}$$

where $I_{it}^{\text{Weeks Post-Rebate}}$ is an indicator for week t being s weeks before or after household i claims the rebate; γ_i, γ_{yr}, and γ_{woy} are household, year, and week-of-year fixed effects; X_t are weather controls. Absent random variation in rebate offers, we can only estimate whether or not installing a water-efficient appliance as part of a rebate program leads to a reduction in water use. We cannot test whether the rebates cost-effectively incentivize households to buy more efficient appliances or to replace their lawns, or else whether these households would have installed the appliances anyways. At the end of this section we conduct a bounding exercise assessing rebates' cost-effectiveness based on different counterfactual assumptions.

Figure 12 plots coefficients from estimating equation (5), while Table II reports coefficients on the simple indicators for days after rebate receipt. Table II shows that installing low-flow toilets results in a 8% reduction (38 gallons) in daily water use.[13] We also estimate a 7% reduction in water use after lawn replacement; however, our estimates are imprecise due to the small sample and heterogeneity in lawn characteristics. Finally, we find evidence of rebound effects after the installation of water-efficient clothes washers, consistent with the previous literature (Bennear, J. M. Lee, and Taylor, 2013; M. Lee, Tansel, and Balbin, 2011; M. Lee, Tansel, and Balbin, 2013; L. W. Davis, 2008).

This section finds that households decrease water use after installing water-efficient toilets in the presence

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[13] The toilet specification data on the rebate forms is highly incomplete. Assuming the new toilets reduced the per-flush water use from 10 gal/flush to 4 gal/flush, a 38 gallon reduction in a day implies six flushes per day, on average.

of a rebate program. But is the program cost-effective? Suppose all households that adopt the rebates are marginal, that is they would not have installed the appliance in the absence of the subsidy. If we assume the marginal cost of water is \$1.71 per 1,000 gallons[14] and that a water-efficient toilet can last 15 years, then our estimates imply that toilet rebates of \$100 have a positive rate of return of around 256%. On the other hand, if we assume that only 10% of customers were induced to purchase appliance by the rebates, then with the same assumptions, the corresponding rate of return for toilet rebates is negative at -64%.

5 The Policies' Impact on Total Water Conservation

This section analyzes the contribution of each of the policies discussed in Section 3 simultaneously in a unified linear regression framework. Specifically, we estimate the following equation:

$$\begin{aligned} y_{it} =& \beta^1 \text{IHS(Rate)}_{it} \\ &+ \beta^2 \text{PostScheduleChange}_t + \beta^3 \text{PostScheduleChange}_t \times \text{Summer}_t \\ &+ \beta^4 \text{Drought Interest}_t \\ &+ \gamma_i + \gamma_{woy} + f(\text{Weather}_t) + \varepsilon_{it} \end{aligned} \tag{6}$$

where y_{it} is the inverse hyperbolic sine (IHS) of household i's average daily use during week t, IHS(Rate)_{it} is alternatively the IHS of average rate or the sum of the IHS of marginal and fixed rates, $\text{PostScheduleChange}_t$ is an indicator for days after the schedule change, and $\text{Drought Interest}_t$ is our measure of Google searches related to the drought. In this specification, we omit year fixed effects to enable estimation of the long-run effects of our policies. Table III presents estimates from this regression with average rates in Columns 1-2 and marginal and fixed rates in Columns 3-4.

These regressions estimate large long-term impacts of the schedule change all-year-round, in the order of 21 to 24%. Moreover, Table III shows that when we control for simultaneous policies, we estimate a price elasticity of water demand of 20% with respect to marginal rates, and of 44% with respect to average rates. Finally, we estimate no effect of drought awareness on water conservation after controlling for simultaneous policies. Appendix Table A.III shows that these results are robust to omitting weather controls and to including a fourth-order polynomial in week-of-year instead of fixed effects which is less demanding in our short sample. However, including year fixed effects or polynomials in sample week appears to inflate the estimated effects of changes in water rates and in the outdoor watering restrictions by a factor of three. We

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[14] This is was the rate in the second half of 2016.

believe that year fixed effects artificially partition our sample in discrete units. Moreover, Appendix Table A.IV shows that our estimates are robust to using logarithm transformations of the outcome and the rate variables instead of the inverse hyperbolic sine transformation.

Next, we decompose the total water savings we observe in Fresno between 2013 and 2016 into components attributable to each of the policies analyzed in Table III. First, we calculate 'Actual Changes' in water use each year relative to a baseline prior to any policy change in the first semester of 2013. Then, we compute 'Policy-Induced Changes' by predicting water use each year based on the coefficients in each column of Table III. Specifically, we compute the following equation for each policy:

$$\text{Policy Induced Changes} = \beta(\overline{\text{Policy}_t} - \overline{\text{Policy}_0}) \tag{7}$$

Table IV reports the results of this exercise by year using estimates including marginal and fixed rates.[15] While we overpredict water conservation in all years, our estimates improve over time. Specifically, rate changes appear to explain 33% of the policy-induced water savings in 2016 compared to 2013, while the schedule change explains 65% of those savings.

6 Conclusion

California is likely to experience more droughts in the future due to climate change. By disentangling the impact of different policies on water conservation, this paper provides a helpful toolkit for policy-makers to fight the next drought. To do so, we take different approaches to assessing the impacts of different policies depending on the identifying variation available in the data.

In general, our difference-in-differences estimates find that individual-level policies often adopted by policymakers, such as fines, rebates for water-efficient toilets, and customer service including home audits have relatively large effects on water conservation at the individual level. However, these policies have a quite small impact on aggregate water use due to low penetration. Furthermore, there are important questions about how scalable these policies are since expanding these programs might not be cost-effective if many customers are infra-marginal.

We also estimate the impact of aggregate policies such as outdoor watering restrictions, rate changes, and policies aimed at increasing drought awareness. We use seasonal controls to remove trends, yet we acknowledge the possibility that omitted variables might bias our estimates. Specifically, our analysis supports the hypothesis that increasing rates helps generate conservation. However, plans to repeatedly increase marginal

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[15] Appendix Table A.V reports estimates including average rates.

rates can be viewed as punitive. In addition, low-income customers and small users, who have a more elastic demand and pay a larger share of their income towards utilities, might be disproportionately affected by rate hikes raising equity concerns (Wichman, Taylor, and Haefen, 2016). Increasing marginal rates whilst reducing or holding constant fixed rates divorces revenues from the costs structure of utilities, thus increasing risk.

Finally, we do not find evidence that increased drought awareness due to state-level announcements leads to long-term water conservation. However, identifying the impact of drought-related conservation and media campaign remains an open and crucial question for drought policy going forward.

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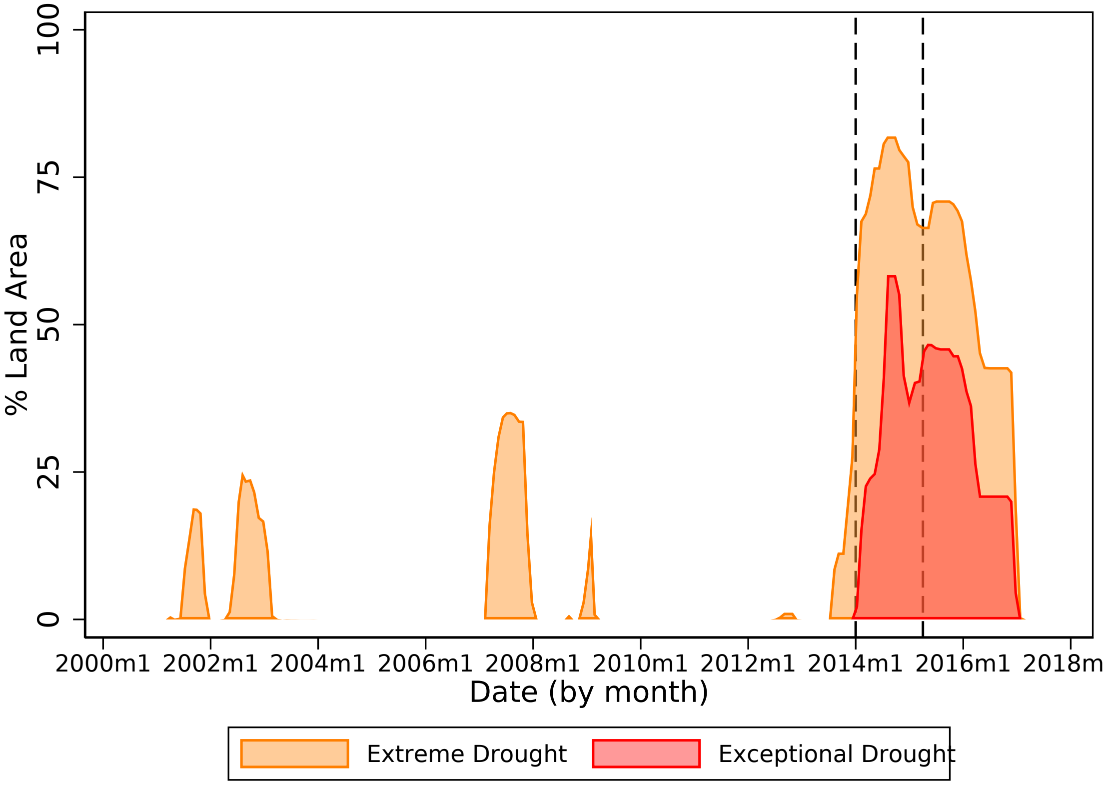
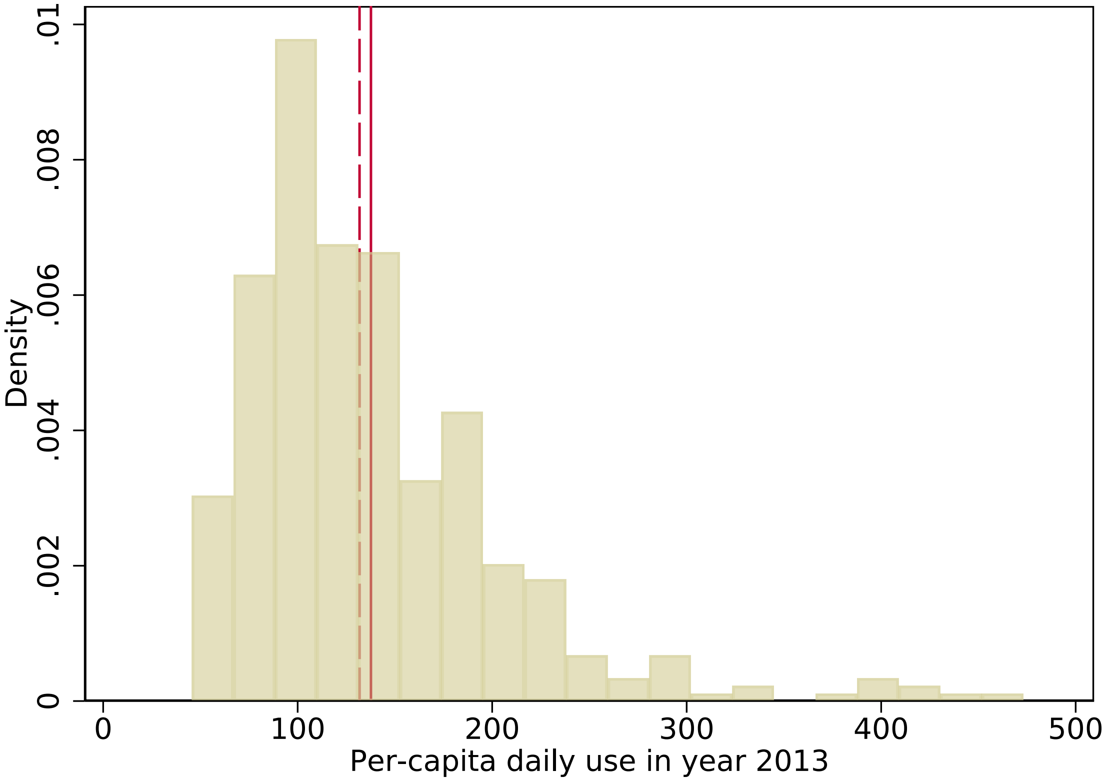
Figures

Figure 1: California Drought Severity



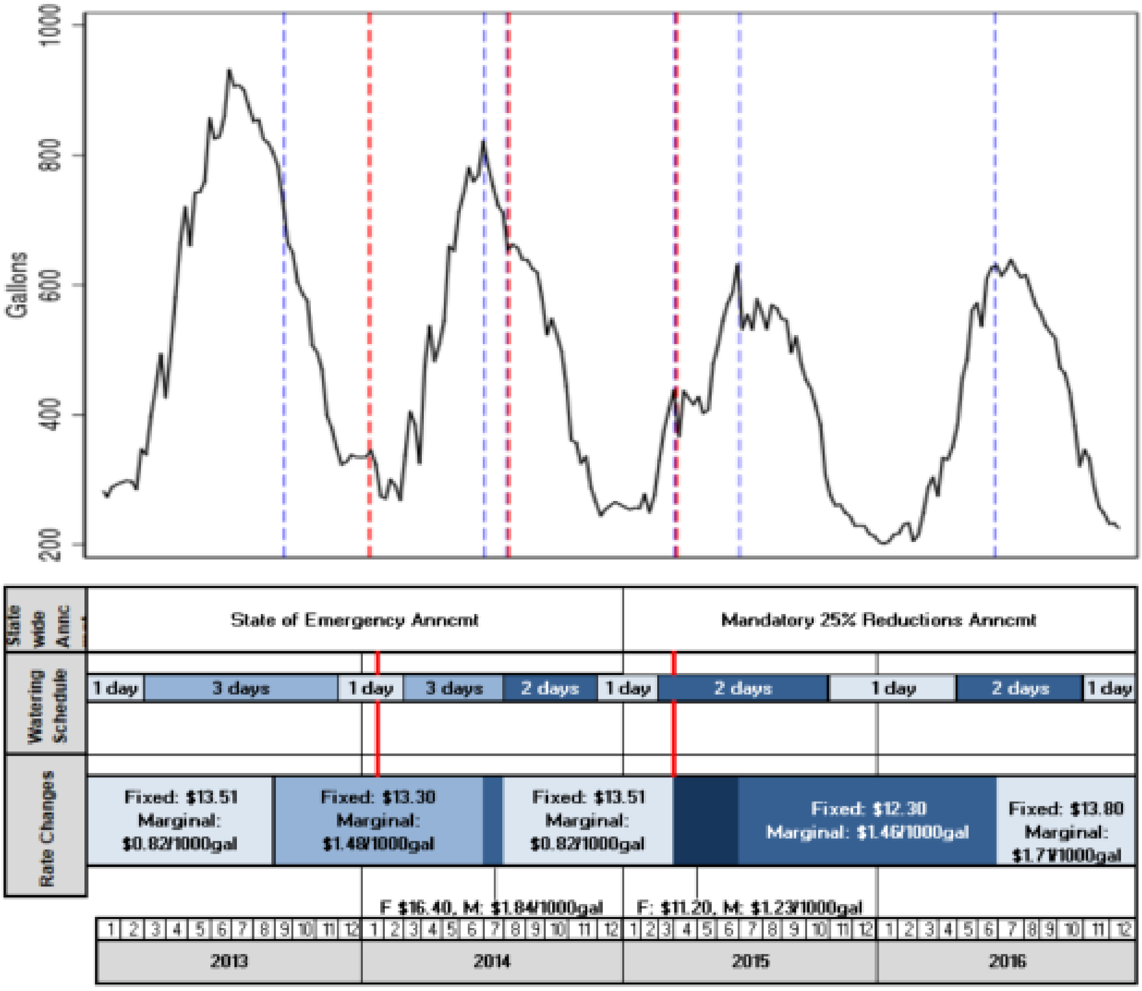
Notes: Using data from the United States Drought Monitor, this figure shows the percent of California in moderate to severe drought from January 2000 to February 2018.

Figure 2: Per Capita Daily Residential Water Use in California in 2013



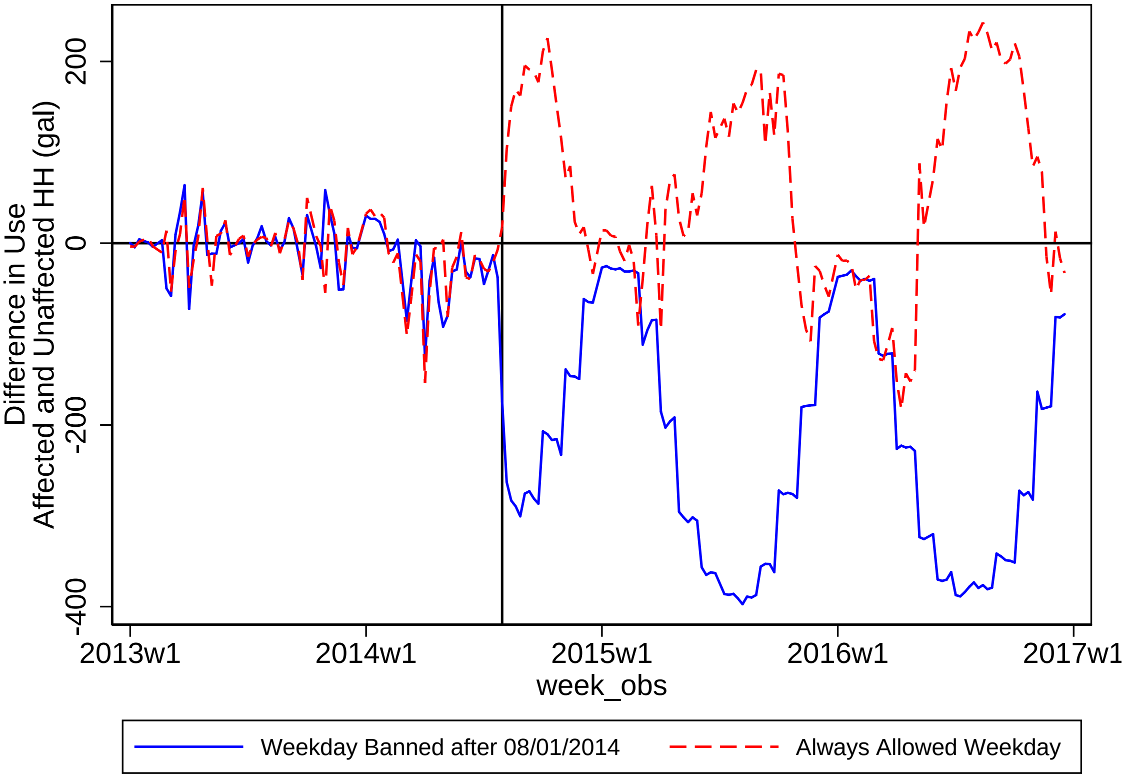
Notes: In this graph, the dashed line represents the average for Fresno (132 gal/day) whereas the solid line represents the average for all utilities in California (138 gal/day). Source: California State Water Resources Control Board, accessed at `https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/conservation_reporting.html` on April 2, 2019. These data include all residential households, whereas the analysis in this paper only includes single-family households.

Figure 3: Average Daily Water Use and Policy Changes in Fresno, 2013-2016



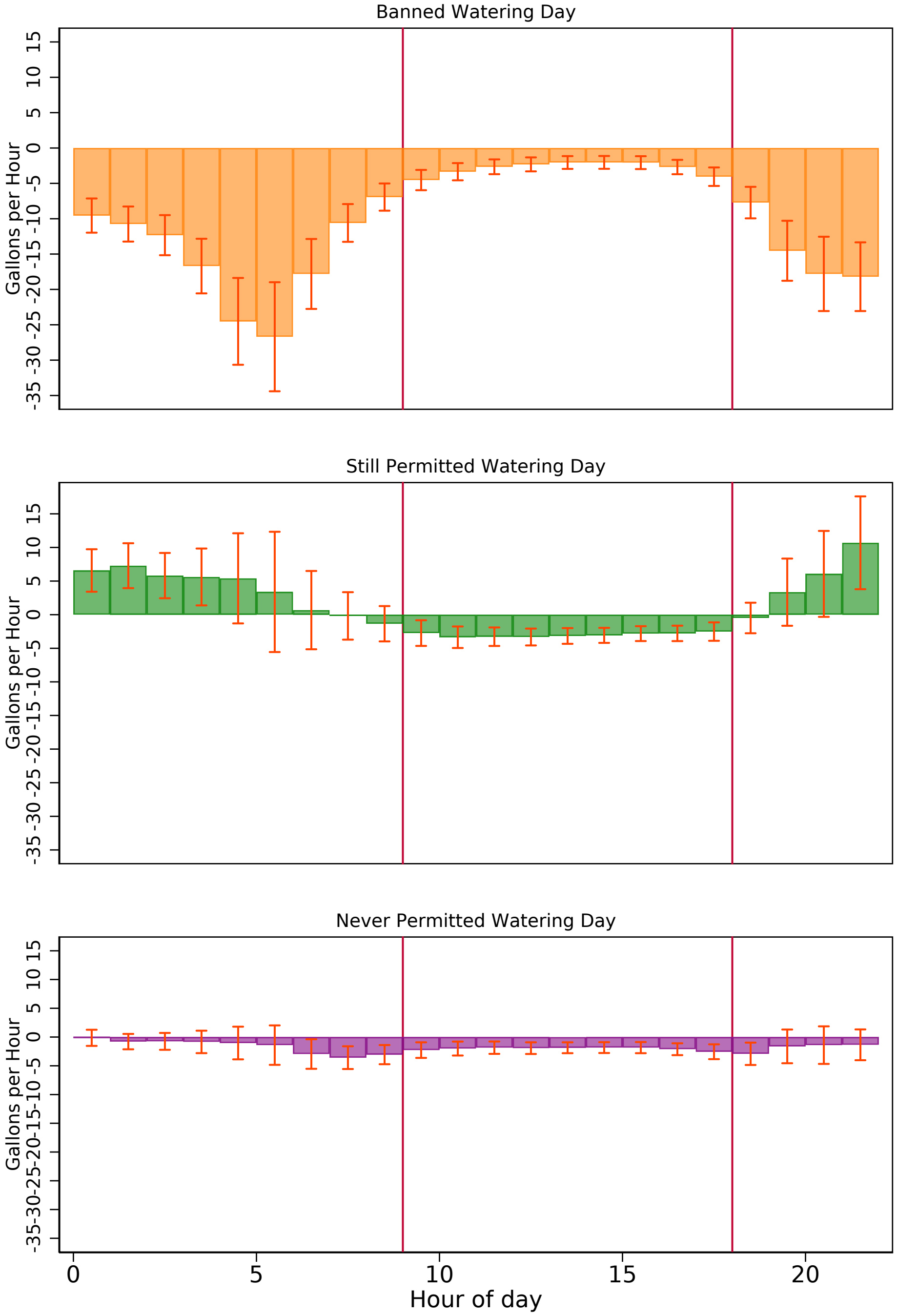
Notes: The top planel of this figure shows average daily water use. The bottom panel shows all of the policy changes we analyse. Red lines in the figure correspond to each statewide announcement was introduced. Blue lines correspond to each rate change.

Figure 4: Substitution after Outdoor Water Use Is Banned on Thursdays and Fridays



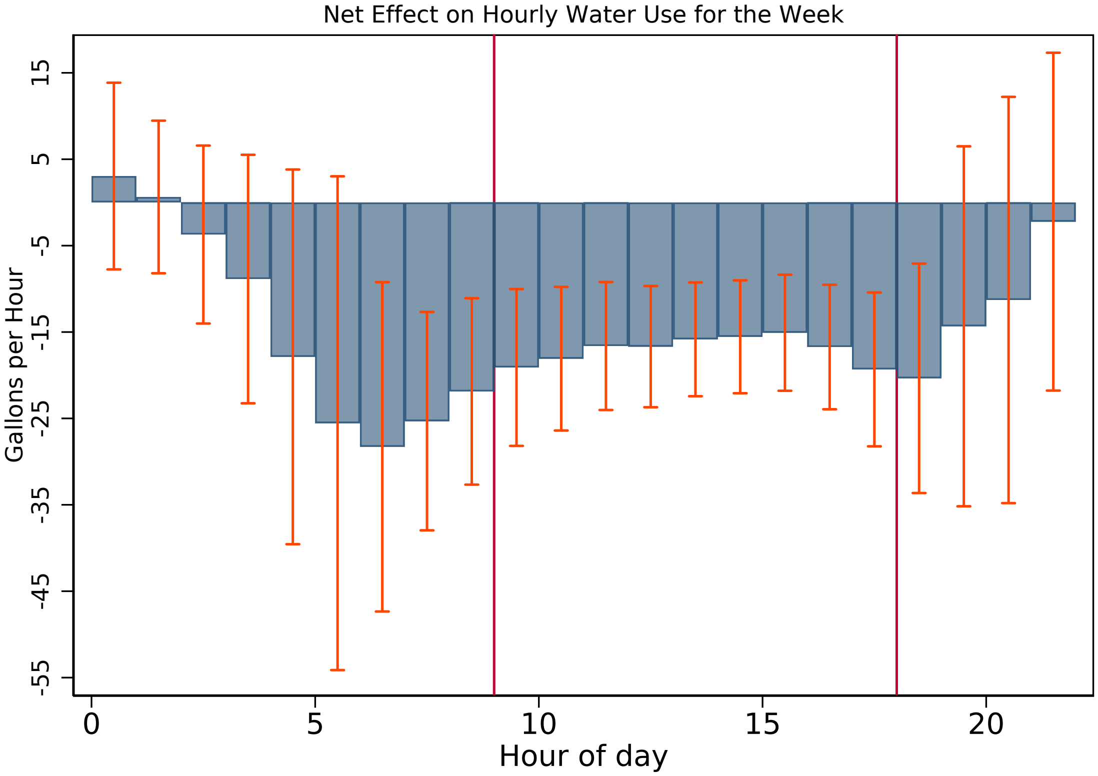
Notes: This figure below plots the difference in water use between i.) even and odd households on Fridays (blue) which is the weekday that became banned for even (it was always allowed for even but banned for odd) and ii.) the difference on Wednesday which remains allowed for even but not odd. Both series partial out interactions between month and day of week in 2013 to remove seasonal baseline differences in water use on these days.

Figure 5: Water Use After Outdoor Schedule Change, by Hour of Day and Day Type



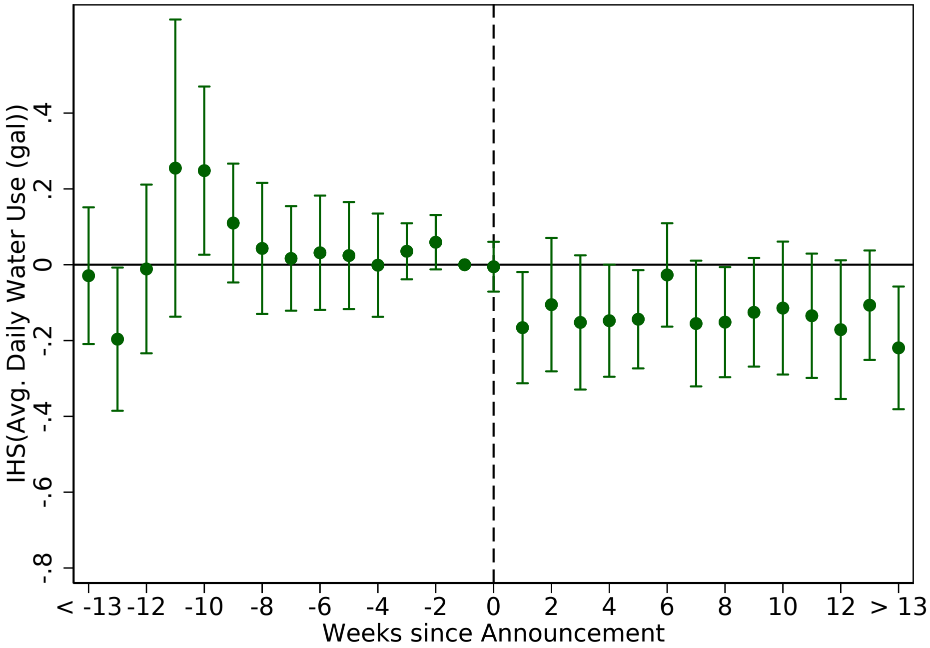
Notes: This figure shows coefficients from hour-by-hour regressions of water use on indicator variables for whether outdoor water-use for a household on that day of the week was either; banned after the policy change, always-permitted, or never-permitted, respectively. Each regression includes indicators for the day of the week, an indicator for post schedule change, and interactions between indicators for “post schedule change” and “banned day”, “remain permitted day”. The regression also controls for whether households live in even-numbered homes, census block group fixed effects, and fixed effects for the day of week, week of year and year. Each regression is weighed by number of households in the census block group. Standard errors are two-way clustered at census block group and sample-month levels. Red lines delimit daytime hours (9 am to 7 pm) when outdoor use is never permitted.

Figure 6: Average Effect of Schedule change on Use, by Hour



Notes: This figure calculates the average hour-by-hour impact of schedule change on weekly water use. The averages are calculated from the regression coefficients in Figure 5. The estimates are weighted given that after the schedule change, each week has one day that became banned, two days that were always-permitted, and four days that were never-permitted. The red lines delimit daytime hours (9 am to 7 pm) when outdoor use is never permitted.

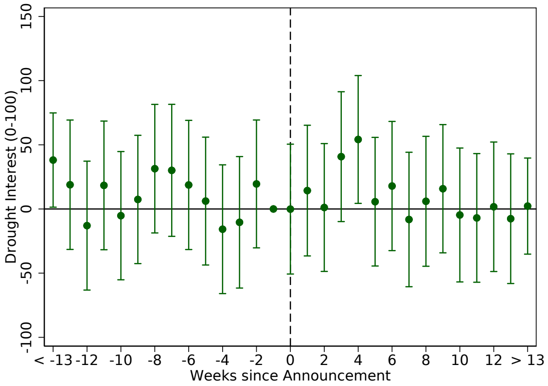
Figure 7: Event-time estimates — the Impact of Outdoor Watering Schedule Change on Water Use



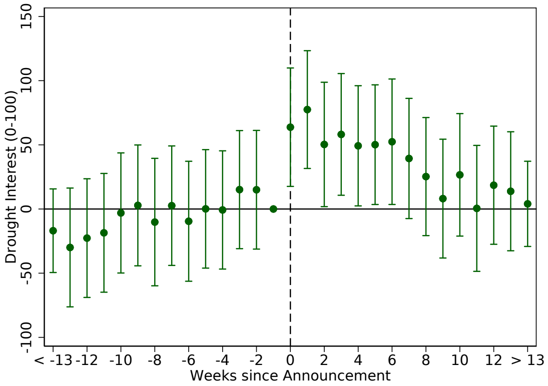
Notes: This figure shows week-by-week event-time coefficients from regressing the inverse hyperbolic sine of average daily water use on indicators for each week relative to the schedule change. The regression includes weather controls, a control for whether summer watering schedule is in place, household fixed effects, and fixed effects in year and week of the year. Standard errors are two-way clustered at household and sample-month levels. The graph shows coefficient estimates and the 95% confidence intervals.

Figure 8: Event-time Estimates — the Impact of Announcements on Drought Interest

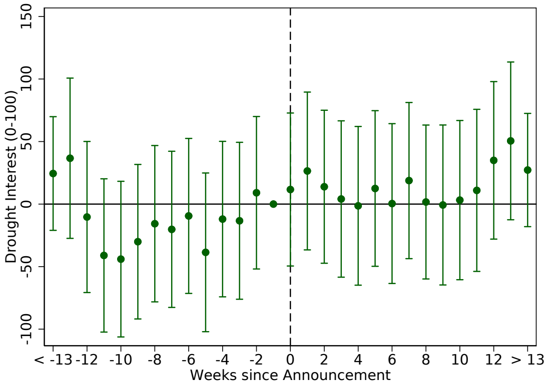
(a) Effect of Outdoor Water Use Schedule Change



(b) Effect of an State of Emergency Announcement



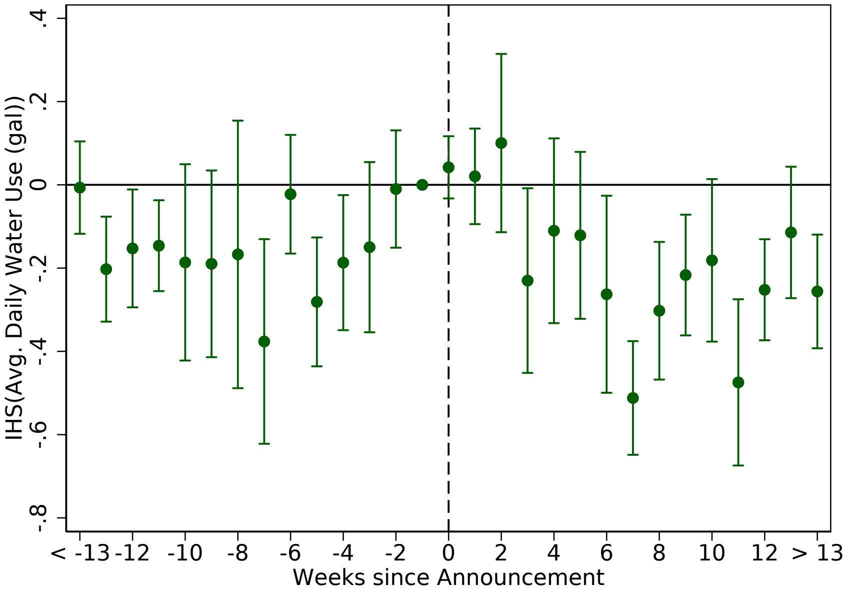
(c) Effect of California Mandated Reductions



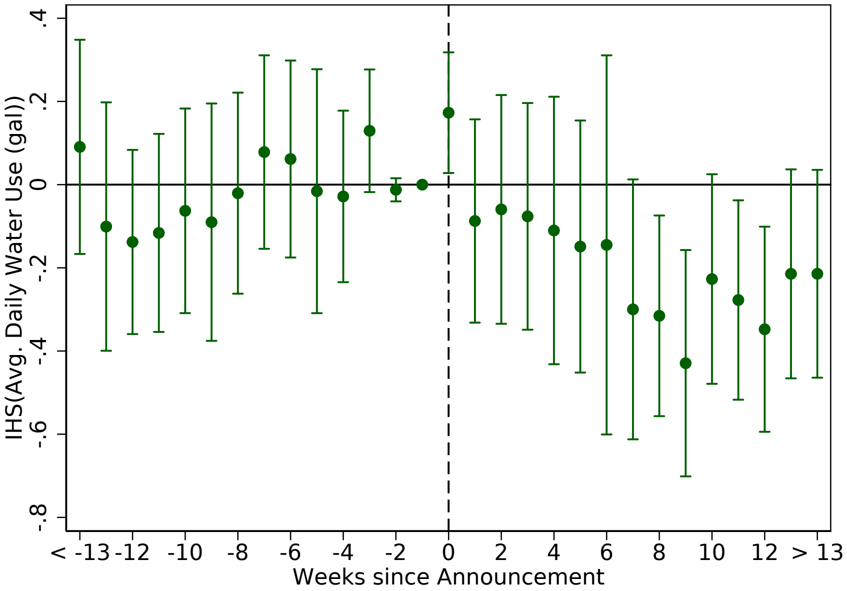
Notes: This figure shows week-by-week event-time coefficients from regressing our drought interest measure obtained from Google searches on indicators for each week relative to the schedule change (top panel), the emergency state announcement (middle panel), and the state-mandated reductions (bottom panel).Each regression includes weather controls, a control for whether summer watering schedule is in place, household fixed effects, and fixed effects in year and week of the year. Standard errors are two-way clustered at household and sample-month levels. Graphs show coefficient estimates and the 95% confidence intervals.

Figure 9: Event-time Estimates — the Impact of State-Wide Conservation Announcements on Water Use

(a) Effect of State of Emergency Announcement

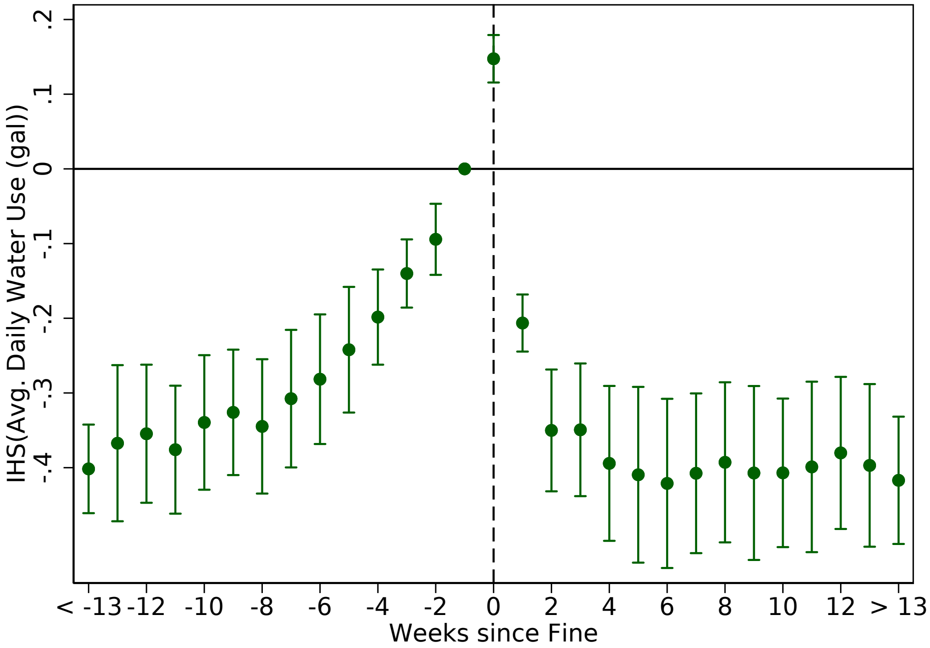


(b) Effect of California Mandated Reductions



Notes: This figure shows week-by-week event-time coefficients from regressing the inverse hyperbolic sine of average daily water use on indicators for each week relative to (a, top panel) Jerry Brown's January 17, 2014 announcement that the drought had placed California in a state of emergency, and (b, bottom panel) California's announcement on Apr 1, 2015 that all municipalities would be collectively required to reduce water use by 25% (top panel), and . Each event-time estimate includes weather controls, a control for whether summer watering schedule is in place, household fixed effects, and fixed effects in year and week of the year. Standard errors are two-way clustered at household and sample-month levels. Graphs show coefficient estimates and the 95% confidence intervals.

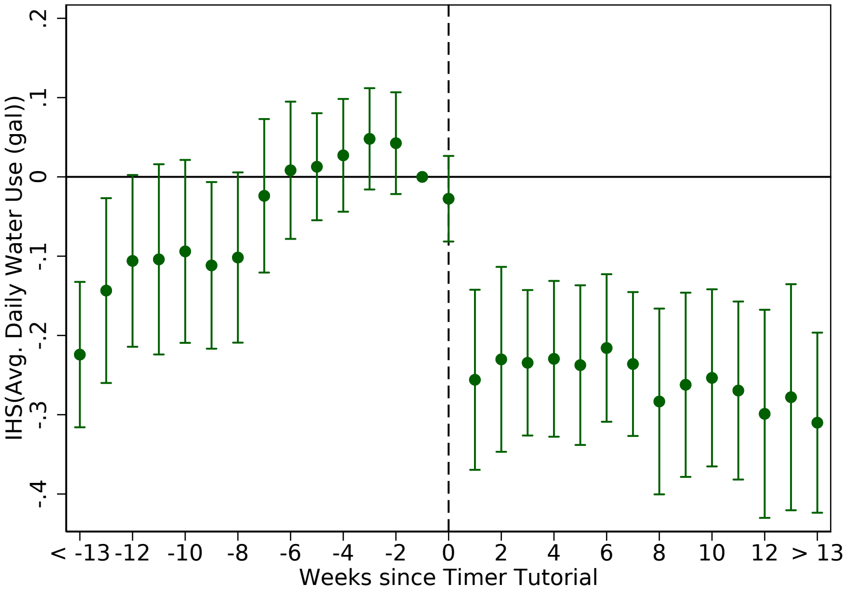
Figure 10: Event-Study Estimates — the Impact of Receiving a Fine



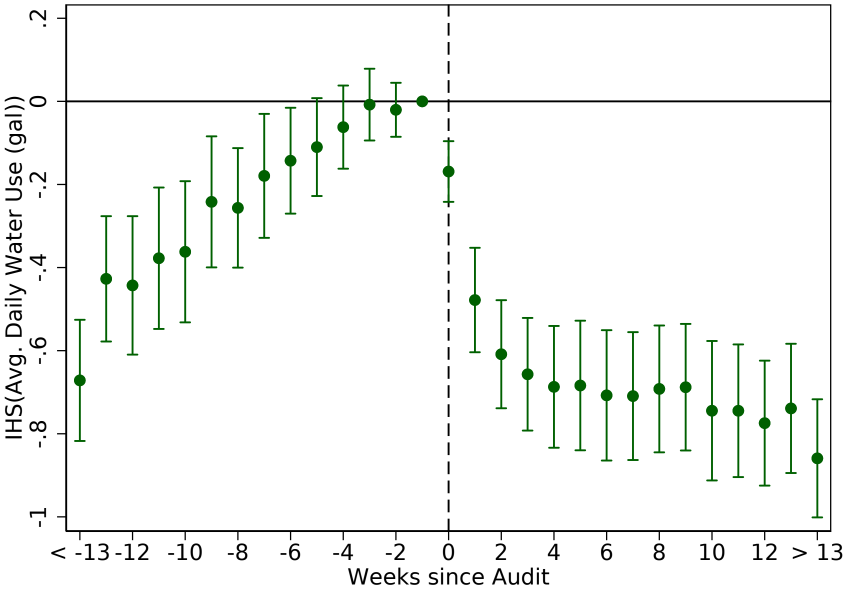
Notes: This figure shows week-by-week event-study coefficients from regressing the inverse hyperbolic sine of average daily water use on indicators for each week relative to a household receiving a fine. This event-study includes weather controls, a control for whether summer watering schedule is in place, household fixed effects, and fixed effects in year and week of the year. Standard errors are two-way clustered at household and sample-month levels. Graphs show coefficient estimates and the 95% confidence intervals.

Figure 11: Event-study Estimates — the Impact of Receiving a Timer Tutorial or Audit

(a) Effect of Receiving a Timer Tutorial



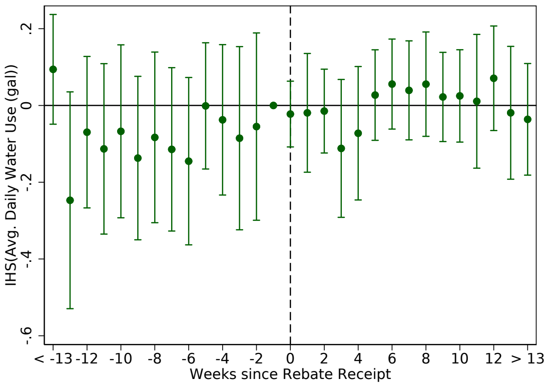
(b) Effect of Receiving an Audit



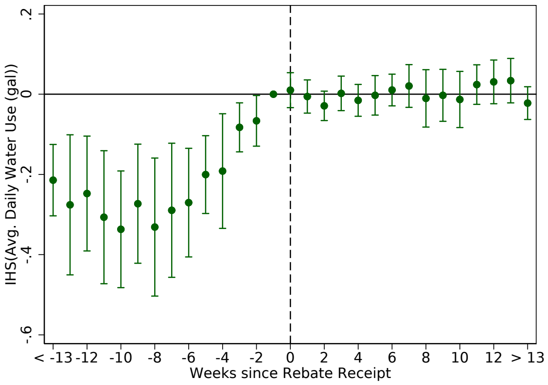
Notes: This figure shows week-by-week event-study coefficients from regressing the inverse hyperbolic sine of average daily water use on indicators for each week relative to a household receiving (a, top panel) a timer tutorial or (b, bottom panel) a water efficiency audit. Each event-study includes weather controls, a control for whether summer watering schedule is in place, household fixed effects, and fixed effects in year and week of the year. Standard errors are two-way clustered at household and sample-month levels. Graphs show coefficient estimates and the 95% confidence intervals.

Figure 12: Event-study Estimates — the Impact of Receiving a Water Efficiency Rebate on Water Use

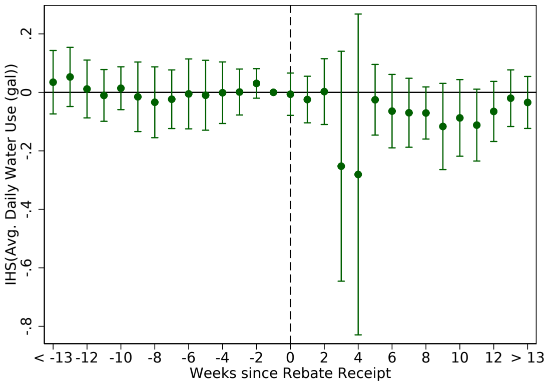
(a) Effect of Receiving a Toilet Rebate



(b) Effect of Receiving a Clothes Washer Rebate



(c) Effect of Receiving a Lawn Replacement Rebate



Notes: This figure shows week-by-week event-study coefficients from regressing the inverse hyperbolic sine of average daily water use on indicators for each week relative to a household receiving (a, top panel) a toilet rebate or (b, middle panel) a clothes washer rebate, or (c, bottom panel) a lawn replacement rebate. Each event-study includes weather controls, a control for whether summer watering schedule is in place, household fixed effects, and fixed effects in year and week of the year. Standard errors are two-way clustered at household and sample-month levels. Graphs show coefficient estimates and the 95% confidence intervals.

Tables

Table I: Elasticity of Average Daily Use

	IHS of Average Daily Use (gallons)				Log of (1+Average Daily Use(gal))			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Average Rate	-0.122		-0.463***		-0.0543		-0.410***	
	(0.121)		(0.159)		(0.0902)		(0.131)	
Marginal Rate		0.0231		-0.206***		0.0162		-0.209***
		(0.0470)		(0.0686)		(0.0386)		(0.0598)
Fixed Rate		1.139***		1.535***		0.913***		1.332***
		(0.208)		(0.171)		(0.153)		(0.145)
Year FE	X	X			X	X		
Observations	17017841	17017841	17017841	17017841	17017841	17017841	17017841	17017841

Notes: The independent variables are inverse hyperbolic sine of Average Rates (AR), Marginal Rates (MR) and Fixed Rates (FR), respectively, in columns (1)-(4), and are logarithm of AR/MR/FR, respectively, in columns (5)-(8). Standard errors in parentheses are two-way clustered at household and sample month level. All regressions include weather controls, an indicator for whether summer watering schedule is in place, household fixed effects, and fixed effects in week of the year. Average rate per gallon is evaluated at household baseline usage.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$

Table II: Impact of Household-level Policies on Water Use

	# Households	Cumulative Counts	IHS of Average Daily Use	
	(1)	(2)	(3)	(4)
After Ticket Received	10,623	13,869	-0.0130	-0.233***
			(0.0249)	(0.0481)
After Timer Tutorial Received	3,333	4,466	-0.0453	-0.202***
			(0.0439)	(0.0540)
After Exterior or Interior Audit	2,594	5,131	-0.208***	-0.381***
			(0.0396)	(0.0434)
After Clothes Washer Rebate Received	1,865	1,872	0.196***	-0.0498
			(0.0465)	(0.0556)
After Toilet Rebate Received	473	501	-0.0862*	-0.300***
			(0.0479)	(0.0570)
After Lawn Rebate Received	190	190	-0.0762	-0.253***
			(0.0479)	(0.0575)
Year FE			X	
Mean of Outcome Variable			468.8	468.8
Observations			17017841	17017841

Notes: Column (1) shows the number of households who every received fine, audit or rebate. Column (2) shows the total number of fines, audits or rebates over the sample period. Column (3) and (4) show regressions estimates of fines, audits or rebates on the inverse hyperbolic sine (IHS) of average daily water use. Each regression includes weather controls, household fixed and week of year effects. Column (3) also includes year fixed-effects. Standard errors in parentheses are two-way clustered at household and sample-month levels

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$

Table III: Simultaneous Impact of City-wide Conservation Policies and Drought Interest on Water Use

	IHS of Average Daily Use (Gallons)			
	(1)	(2)	(3)	(4)
IHS of Average Rate per Gallon	-0.436***	-1.321***		
	(0.0842)	(0.244)		
IHS of Fixed Rate			0.549***	0.503**
			(0.166)	(0.193)
IHS of Marginal Rate per Gallon			-0.197***	-0.399***
			(0.0371)	(0.0731)
Post Schedule Change	-0.360***	-1.023***	-0.331***	-0.600***
	(0.0422)	(0.154)	(0.0399)	(0.104)
Post Schedule Change, Summer	0.0583	0.136***	0.0714	0.104**
	(0.0511)	(0.0459)	(0.0484)	(0.0434)
Drought Interest	-0.0196	-0.0229*	-0.0112	-0.00986
	(0.0133)	(0.0135)	(0.0107)	(0.0138)
Year FE		X		X
Observations	17017841	17017841	17017841	17017841

Notes: Each column presents regression estimates of the effect of city-level policies on the inverse hyperbolic sine (IHS) of average daily water use. Columns (1) and (2) include average rates, while columns (3) and (4) include marginal and fixed rates. Regressions include weather controls, and household and week of year fixed effects. Columns (2) and (4) include year fixed-effects. Standard errors in parentheses are two-way clustered at household and sample-month levels.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$

Table IV: Policies' Contributions to Water Conservation

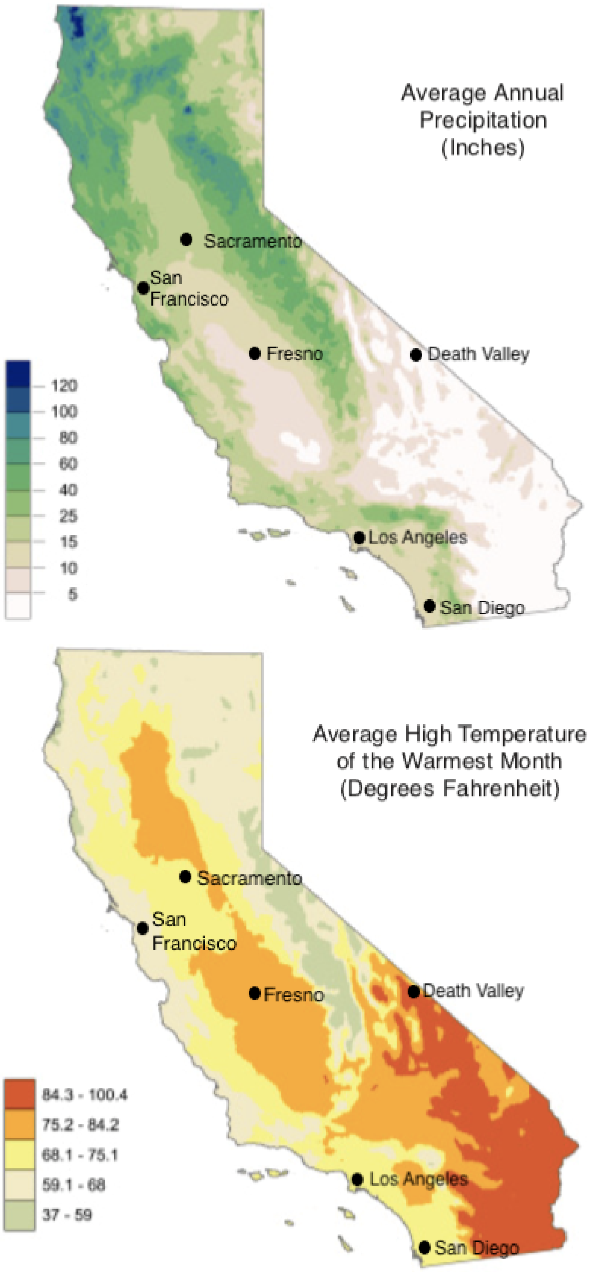
	Year 2014	Year 2015	Year 2016
Outcome: IHS of Water Use			
Actual Change	-0.0996	-0.305	-0.323
Policy-Induced Change	-0.199***	-0.436***	-0.455***
	(0.0278)	(0.0357)	(0.0134)
Policy-Induced Change / Actual Change	199.8%	143.0%	140.9%
% Policy-Induced Change Explained by Each Policy			
Marginal and Fixed Rate Changes	31.43***	30.56***	33.08***
	(6.721)	(4.804)	(5.456)
Schedule Change	61.00***	64.87***	64.79***
	(6.266)	(6.229)	(6.031)
Drought Interest	7.578	4.578	2.131
	(7.305)	(4.413)	(2.054)
Number of Policy Changes			
Rate Changes	2	2	1
Water Schedule Change	1	0	0
Announcements	1	1	0

Notes: The top panel of this table shows the actual and predicted policy-induced change in the inverse hyperbolic sine (IHS) of average daily water use each year relative to the beginning of the sample period in the first semester of 2013. The policy-induced change is computed using the regression coefficients in column (3) of Table III. The middle panel shows contribution of each city-wide policy to the total policy-induced change. The bottom panel shows the number of policy changes in each year. Standard errors in parentheses are two-way clustered at sample-month and household levels.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$

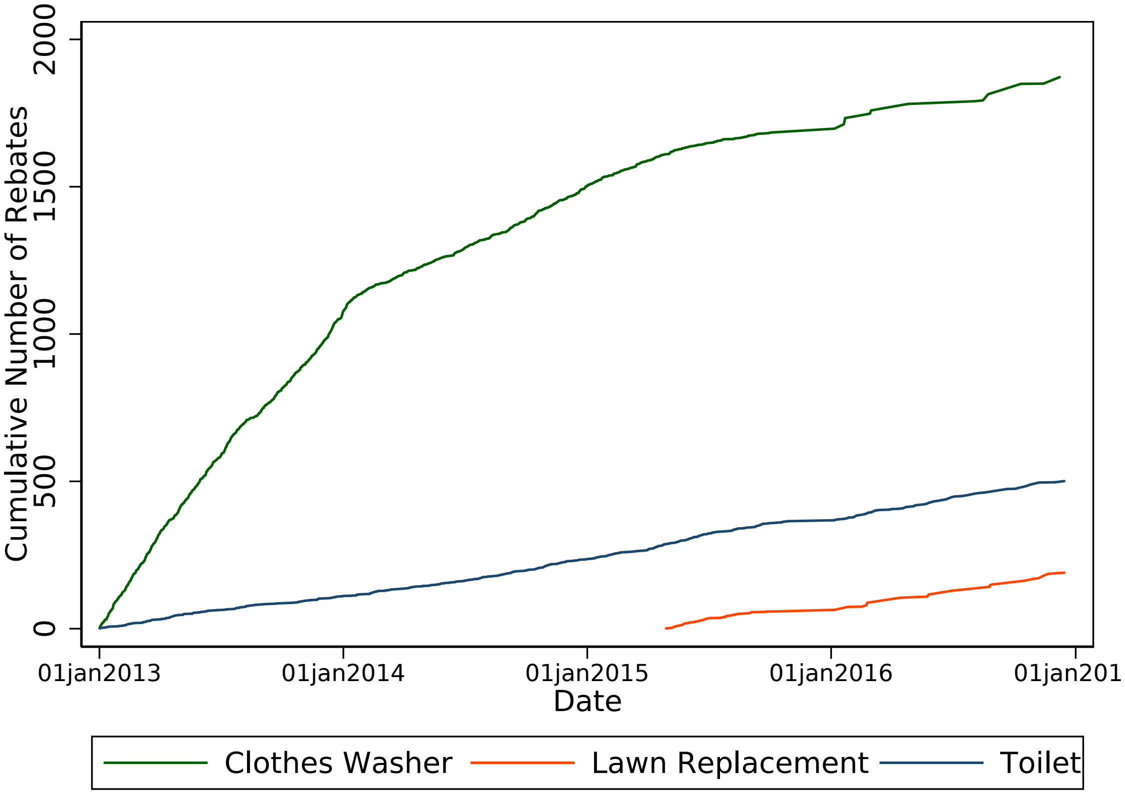
Appendix Figures

Figure A.1: Precipitation and High Temperature in Fresno and California



Notes: Source of map is the California Coastal Commission (`https://www.coastal.ca.gov/coastalvoices/resources/Biodiversity_Atlas_Climate_and_Topography.pdf`, accessed on April 2, 2019)

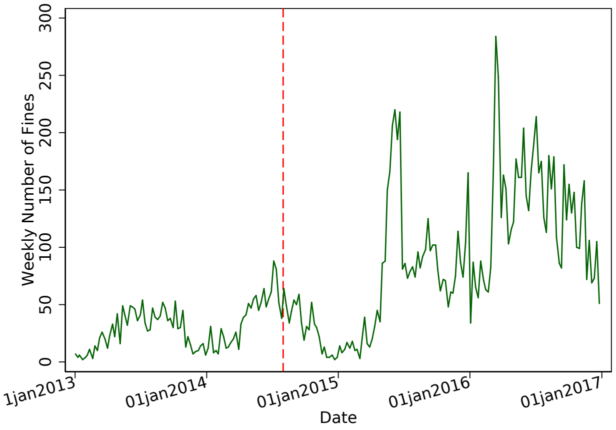
Figure A.2: Rebate Adoption Over Time



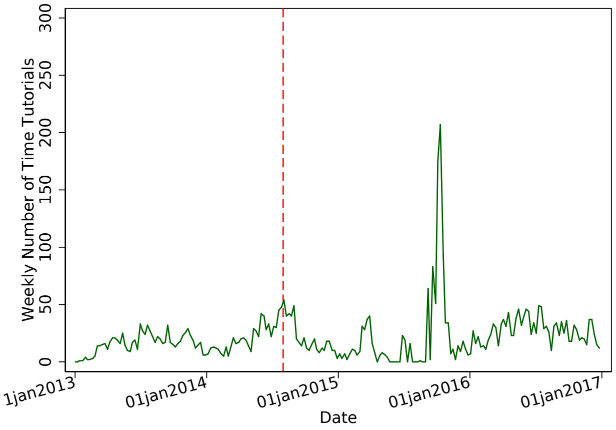
Notes: This plot shows the cumulative number of clothes washer, lawn replacement and toilet rebates issued in Fresno over the sample period. Lawn replacement rebates were introduced in 2015.

Figure A.3: Weekly Counts of Fines, Timer tutorials, and Audits in Fresno

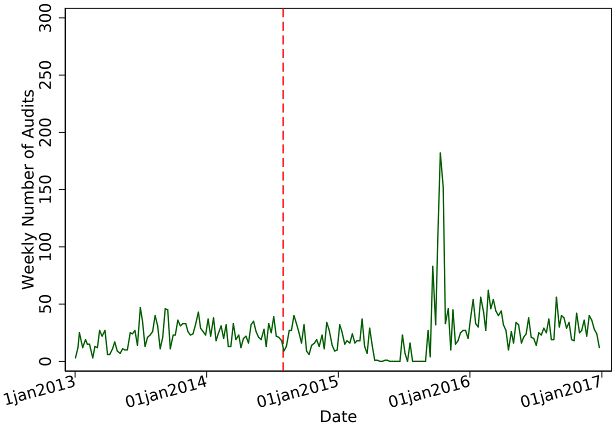
(a) Weekly Number of Fines



(b) Weekly Number of Timer Tutorials

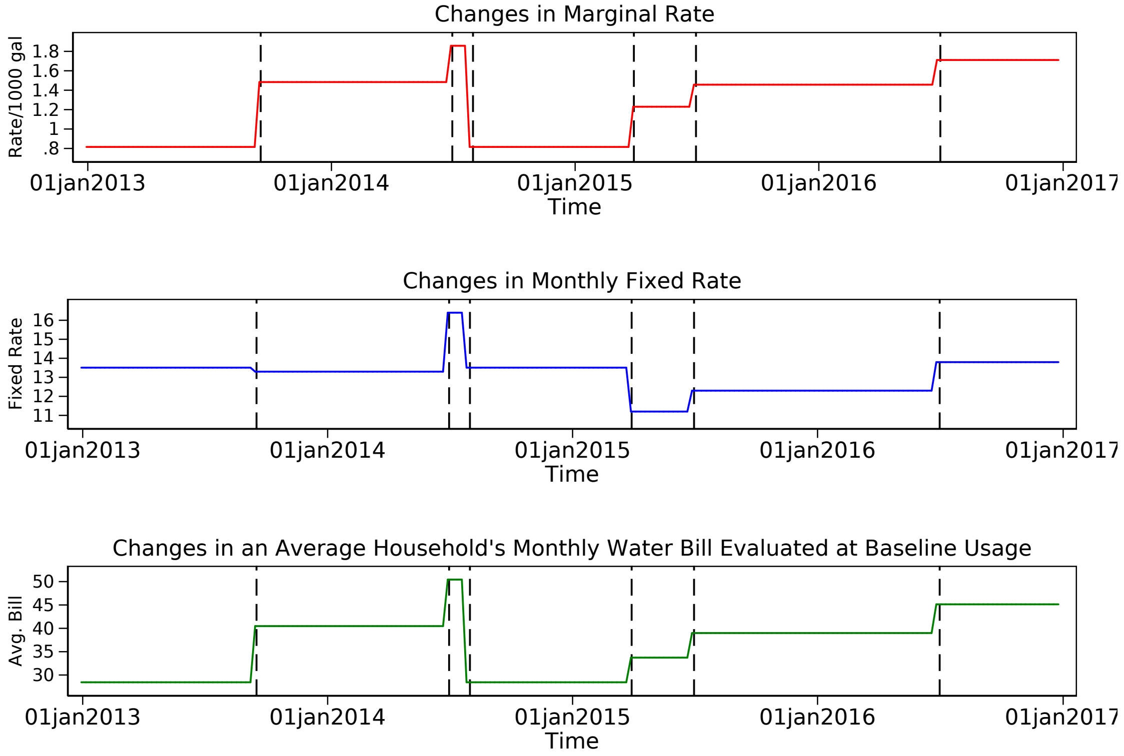


(c) Weekly Number of Audits



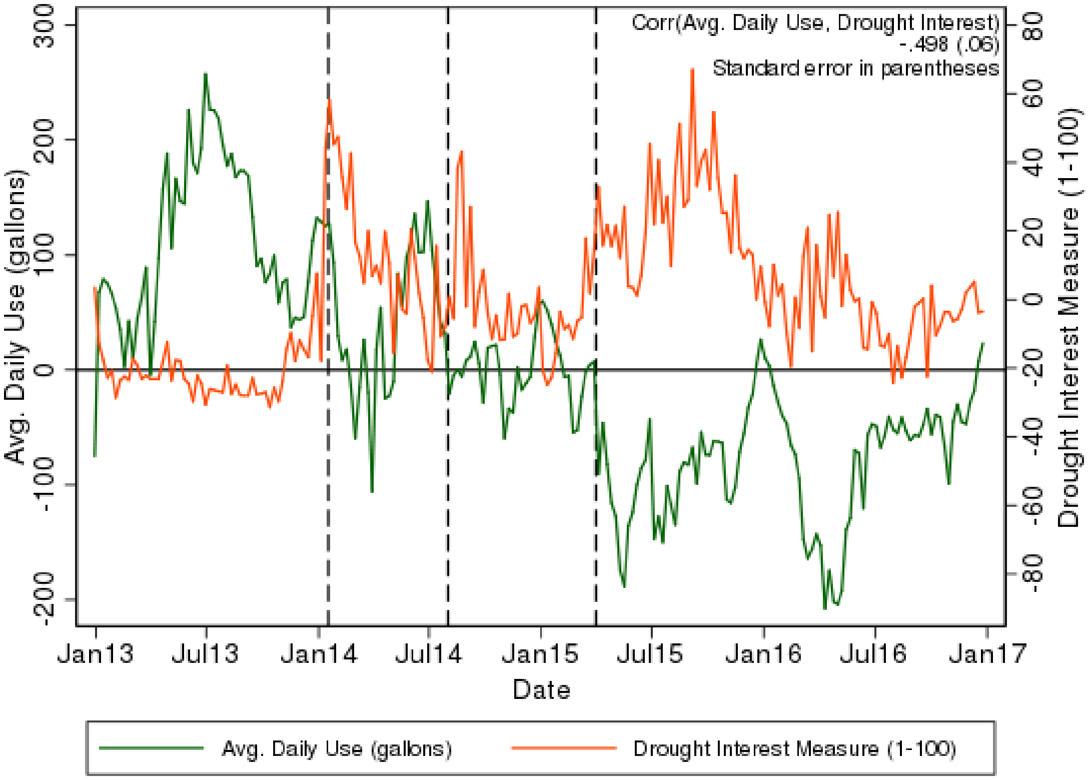
Notes: The top, middle and bottom figures respectively show the weekly number of fines, timer tutorials, and audits issued in Fresno in throughout the sample period. The red line is the date of the schedule change on August 1, 2014.

Figure A.4: Rate Changes between 2013 and 2016



Notes: The top, middle and bottom figures respectively show changes in the marginal, fixed and average rates charged throughout the sample period. Fixed rates shown only for 1” sized water meter. Average rates are calculated based on the households monthly water use at the beginning of the sample period.

Figure A.5: Drought Interest and Water Use over Time



Notes: This figure plots a weekly times series of de-seasoned average daily water use and drought interest. The drought interest measure is computed from Google searches for the word “drought”. Vertical lines indicate dates of the State of Emergency announcement, the outdoor watering schedule change, and the mandated restrictions.

Appendix Tables

Table A.I: Summary statistics

	California	Fresno	Rank in California
Demographics			
Population	38,066,920	506,132	5
Average household income	86,704	58,219	88
Median household income	61,489	41,455	95
Fraction of bachelor's degree or more	19.60%	20.10%	69
Average household size	2.95	3.10	44
Fraction of home-owners	54.80%	46.06%	82
Average Per Capita Residential Water Use (gal/day)			
Year 2013	138	132	35
Year 2014	129	122	39
Year 2015	98	105	24
Year 2016	97	120	14
Climate Characteristics (2013-2016)			
Average Precipitation (inches/day)	0.0615	0.0256	39
Average Daily High Temperature (F)	72.62	80.89	46
Average Daily Low Temperature (F)	47.10	53.73	11

Notes: This table shows summary statistics on demogrpahics, average water use and climate in California and Fresno, as well as Fresno's rank within the 100 largest water utilities in California. Demographics statistics are from 2014 ACS 5-year estimates. Income-related statistics are in 2014 inflation-adjusted dollar. Average per capita daily water use data is from California State Water Resources Control Board data. (Accessed at `https://www.waterboards.ca.gov/water_issues/programs/conservation_portal/conservation_reporting.html` on April 2, 2019). Data before July 2013, and most data before October 2014 is imputed. Climate characteristics are from NOAA National Climatic Data Center (Accessed at `https://www.ncdc.noaa.gov/cdo-web/search` on April 3, 2019).

Table A.II: Outdoor Water Use Schedule Before and After August 2014

		Odd				Even			
Day	Type of Day	Summer		Winter		Summer		Winter	
		Before	After	Before	After	Before	After	Before	After
Monday	Always Banned	.	.	.	.	.	.	.	.
Tuesday	Always Allowed Summer Day	X	X	.	.	.	.	.	.
Wednesday	Always Allowed Summer Day	.	.	.	.	X	X	.	.
Thursday	Banned after 08/01/2014	X	.	.	.	.	.	.	.
Friday	Banned after 08/01/2014	.	.	.	.	X	.	.	.
Saturday	Always Allowed	X	X	X	X	.	.	.	.
Sunday	Always Allowed	.	.	.	.	X	X	X	X
	Total Watering Days	3	2	1	1	3	2	1	1

Notes: This table shows which days each household is permitted to use water outdoors both before and after the schedule change based on whether their house is odd- or even-numbered. On permitted days, marked with an X, households may use water outdoors but only before 9am in the morning or after 6pm in the evening.

Table A.III: Alternative Specifications of Simultaneous Impact of City-wide Conservation Policies and Drought Interest on Water Use

	IHS of Average Daily Use (gallons)					
	(1)	(2)	(3)	(4)	(5)	(6)
IHS of Average Rate per Gallon	-0.386***	-0.415***	-1.288***			
	(0.0845)	(0.0812)	(0.278)			
IHS of Fixed Rate				0.572***	0.433**	-0.279
				(0.187)	(0.164)	(0.520)
IHS of Marginal Rate per Gallon				-0.170***	-0.190***	-0.501
				(0.0390)	(0.0384)	(0.344)
Post Schedule Change	-0.394***	-0.373***	-1.143***	-0.363***	-0.349***	-0.898**
	(0.0478)	(0.0439)	(0.202)	(0.0435)	(0.0422)	(0.413)
Post Schedule Change, Summer	0.0878	0.0711	0.598***	0.102*	0.0855*	0.588***
	(0.0596)	(0.0496)	(0.0553)	(0.0550)	(0.0457)	(0.0907)
Drought Interest (standardized)	-0.0316**	-0.0180	-0.00342	-0.0231*	-0.0120	-0.00924
	(0.0141)	(0.0151)	(0.0293)	(0.0119)	(0.0134)	(0.0499)
Observations	17017841	17017841	17017841	17017841	17017841	17017841
Weather Controls		X	X		X	X
Week of Year FE	X			X		
4th Polynomial in Week of Year		X			X	
4th Polynomial in Sample Week			X			X

Notes: This table calculates the same results as Table III, except using alternative sets of controls to test for robustness. Columns (1) and (4) include week of year fixed effects but not weather controls. Columns (2) and (5) include a fourth order polynomial in Week of Year and Weather Controls. Columns (3) and (6) include a fourth order polynomial in sample week and weather controls. All regressions include household fixed effects. Standard errors in parentheses are two-way clustered at household and sample-month levels.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$

Table A.IV: Simultaneous Impact of City-wide Conservation Policies and Drought Interest on Log Water Use

	Log of (1+Average Daily Use(gal))			
	(1)	(2)	(3)	(4)
Log of Average Rate per Gallon	-0.407***	-0.872***		
	(0.0569)	(0.156)		
Log of Fixed Monthly Rate			0.437***	0.339**
			(0.117)	(0.152)
Log of Marginal Rate per Gallon			-0.217***	-0.326***
			(0.0267)	(0.0597)
Post Schedule Change	-0.335***	-0.706***	-0.307***	-0.484***
	(0.0395)	(0.104)	(0.0375)	(0.0879)
Post Schedule Change, Summer	0.0412	0.0817*	0.0465	0.0656
	(0.0480)	(0.0412)	(0.0456)	(0.0405)
Drought Interest (standardized)	-0.0102	-0.0276**	0.000652	-0.0148
	(0.0108)	(0.0116)	(0.00924)	(0.0118)
Observations	17017841	17017841	17017841	17017841
Year FE		X		X

Notes: This table calculates the same results as Table III, except using the log(1+ average daily water use), rather than the IHS. Each column presents regression estimates of the effect of city-level policies on the log of average daily water use. Columns (1) and (2) include average rates, while columns (3) and (4) include marginal and fixed rates. Regressions include weather controls, and household and week of year fixed effects. Columns (2) and (4) include year fixed-effects. Standard errors in parentheses are two-way clustered at household and sample-month levels.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$

Table A.V: Policies' Contributions to Water Conservation (Specification with Average Rate Changes)

	Year 2014	Year 2015	Year 2016
Outcome: IHS of Water Use			
Actual Change	-0.0996	-0.305	-0.323
Policy Induced Changes	-0.253***	-0.438***	-0.507***
	(0.0205)	(0.0300)	(0.0418)
Policy-Induced Change / Actual Change	254.0%	143.6%	157.0%
% Policy-Induced Change Explained by Each Policy			
Average Rate Changes	34.68***	18.74***	31.49***
	(6.695)	(3.618)	(6.079)
Schedule Change	54.89***	73.28***	65.17***
	(5.361)	(6.730)	(5.827)
Drought Interest	10.43	7.975	3.343
	(7.086)	(5.416)	(2.270)
Number of Policy Changes			
Rate Changes	2	2	1
Water Schedule Change	1	0	0
Announcements	1	1	0

Notes: This table shows the same calculations as Table IV, but in terms of average rates rather than marginal and fixed rates. The top panel of this table shows the actual and predicted policy-induced change in the inverse hyperbolic sine (IHS) of average daily water use each year relative to the beginning of the sample period in the first semester of 2013. The policy-induced change is computed using the regression coefficients in column (1) of Table III. The middle panel shows contribution of each city-wide policy to the total policy-induced change. The bottom panel shows the number of policy changes in each year. Standard errors in parentheses are two-way clustered at sample-month and household levels.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.010$