Evaluating Water Conservation Policy in California

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Abstract

Between 2014 and 2016, California required urban water districts to conserve 20-25% of the water used across the state in 2013. While some districts were very successful, others failed to meet their targets. What explains variation in California urban water districts' success when state-wide mandatory water reductions were in effect? Using an original monthly panel data set, we examine how variation in policy—pricing, messaging and penalties—affected water conservation across districts. We find marked differences across high and low performing districts in the strategies they use to save water. Using fixed effects estimators, we find that social penalties alone substantively contributed to water conservation. By contrast, both messaging strategies and pricing strategies did not appear to increase water savings. We conclude that California should adopt a more comprehensive data collection and accountability system to increase water conservation effectiveness and water price equality across the state.

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Introduction

California recently concluded a record drought that lasted over five years. In the midst of the drought, Governor Jerry Brown issued an executive order in April 2014, calling on urban water districts to reduce consumption by 20% over 2013 levels. In April 2015, the Governor increased the conservation target, calling for a statewide reduction of 25%. To meet this new conservation, the State Water Resources Control Board (SWRCB) placed urban water suppliers into specific conservation tiers based on past performance.[1] Throughout 2014 and 2015, some districts' efforts proved very successful, with savings over 50%, while others only managed 5% (Palazzo et al., 2017). Overall, 55% of reporting urban water districts met their tier target goal when the Governor lifted mandatory reductions in February 2016.

Rather than requiring specific policies to save water, California took a decentralized approach, with different districts adopting varying conservation strategies. Water districts have a number policy levers to influence residential water consumption. Yet, we have very little information on which strategies work best to change behavior and increase water conservation. What explains variation in California's urban water districts' ability to conserve water? In this project, we aim to evaluate the effectiveness of a number of policy strategies: pricing, messaging and penalties.

First, we might expect change that increasing the cost of water could increase conservation. We might also expect subsidies for long-term changes, like replacing lawns or appliances, to decrease consumption. Second, significant psychology and public policy research suggests that simple information messaging may fail to change behavior, while social norms messaging can be very effective. Third, we might expect penalties to change behavior. To test these theories, we collected data from water districts on various pricing strategies, from cost increases to rebates; how water districts are communicating with customers, including providing individual feedback and comparison information; and penalties, collecting data on whether monetary or public penalties were issued, and if so how many over time.

[1] Governor's Resolution No. 2015-0032

To examine how policy changes affect water conservation, we collected an original, monthly panel data set of California's urban water districts. Our data set spans the entire period that mandatory drought reductions were in effect. We analyze the data both cross-sectionally, comparing across higher and lower water conservation districts, as well as by using fixed effects regressions, which compare within a given district over time. In both approaches, the goal is to identify which policies are driving water conservation, enabling districts to meet or fail to meet their targets.

We find marked differences across high and low performing districts in the strategies they use to save water. The best performing districts are twice as likely to use social penalties than the worst-performing districts. Top water districts also have nearly 50% higher water bills on average. Although our fixed effects model results are preliminary given data availability, we find social penalties are effective at driving water conservation while pricing and information provision are not. We conclude that decentralized water governance may hamper California's ability to address water scarcity, as climate change accelerates the occurrence of drought. We recommend greater reporting requirements and accountability to the State Water Board, as well as best practices sharing to increase water districts' capacity.

Background on Water Conservation in California

During its record drought, California allowed urban water districts to adopt various water conservation strategies rather than requiring specific policies and strategies to save water. In practice, the State Water Resources Control Board (SWRCB) was responsible for implementing the statewide conservation standards that Governor Brown announced in April 2014 and 2015. The SWRCB placed specific urban water districts into an array of conservation tiers in response to Governor Brown's call for a new 25% statewide conservation standard.[2] As the Governor's executive order directed, conservation targets were assigned

[2]Nine conservation tiers were formed, ranging from 4% to 36% in increments of 4 percentage points (Tier 1: 4%; Tier 2: 8%; Tier 3: 12%; Tier 4: 16%; Tier 5: 20%; Tier 6: 24%; Tier 7: 28%; Tier 8: 32%; Tier 9:

to each urban water district based on relative per capita usage during the 2014-2015 water year. Districts which outperformed their peers' conservation in previous years were placed in tiers with lower conservation targets; districts performing poorly were assigned higher conservation targets.[3] Districts were allowed to comment upon tier-assignment between April 21 and April 28 before the tier targets were implemented on May 5, 2015.

Neither Governor Brown nor the SWRCB mandated that districts adopt a fixed set of conservation strategies to achieve the conservation targets during 2014 or 2015. Instead, districts were encouraged to pursue water conservation strategies particular to their local challenges (SWRCB, 2015). Thus, urban water suppliers bore the responsibility for figuring out how to achieve their goals. This arrangement is not surprising given the institutions involved. Urban water suppliers are special districts that operate autonomously from the governments which sanctioned them, are geographically flexible, and limited in scope to a single policy issue (Mullin, 2009). Intended to facilitate more effective, representative, and adaptive governance, special districts are formed to optimize local public goods provision. Thus, special districts are fragmented and technocratic by nature. These characteristics allegedly make special districts resistant to the electoral and private incentives that misalign local demands and policy-outcomes. In this way, special districts represent a bottom-up approach to natural resource governance (Ostrom, 1990; Gleick, 2002, 2003).

Yet little empirical evidence exists which evaluates the practical effectiveness of decentralized governance via special districts. Sara Hughes finds that special districts in California were more willing to enroll in voluntary statewide urban water conservation programs, but proved no more effective in conserving water than urban water suppliers which did not enroll in the program (Hughes, 2012).

Moreover, there is little theoretical consensus regarding the effectiveness of special district

36%. Conservation was assessed cumulatively from June 2015 onward, based on monthly usage in 2013.

[3]See Directive 2 in Governor Brown's proclamation: "...restrictions will require water suppliers to California's cities and towns to reduce usage as compared to the amount used in 2013...consider[ing] the relative per capita water usage of each water suppliers' service area, and require that those areas with high per capita use achieve proportionally greater reductions than those with low use"(Brown, 2015).

governance. One perspective holds that special districts are just as, if not more, vulnerable to interest group capture as elected institutions. In this view, they are unaccountable to the local publics they claim to serve (Axelrod and Keohane, 1986; Bollens, 1957). Conversely, public choice theory argues that by facilitating issue-specific communication between district officials and citizens and by promoting functional specialization, special districts are more flexible and responsive to their constituents' specific demands (Ostrom et al., 1961, 1988; Ostrom, 1972). However, both perspectives cite anecdotal evidence and treat special districts as apolitical: neither account for variation across districts in terms of structure, function, and authority (Mullin, 2009).

Megan Mullin (2009) has shed some light on this puzzle. Examining water districts nationwide, Mullin advances a conditional theory of specialized governance. Mullin contends that issue salience and issue-public mobilization dually determine the effectiveness of special district governance (Mullin, 2009). As special districts—and their policy-domain—become more salient, they typically become more responsive to public demands. By contrast, district officials are typically appointees and thus less-accountable by definition to public demands when issue-salience and public mobilization is low. Under these conditions, incentives for intergovernmental cooperation are limited and special districts are particularly vulnerable to interest group capture (Mullin, 2009).[4]

If we want to understand the effectiveness of various policies, this decentralized institutional structure provides significant advantages. If individual special districts choose autonomously whether and when to adopt policies, there should be significant variation in their timing and implementation across districts. This variation provides significant leverage for identifying special districts' policy effectiveness. Unfortunately, the autonomy also creates significant data quality and availability challenges.

Water districts have a number of tools at their disposal to try to change residential wa-

[4]However, the nature of this capture is dissimilar to the type of pro-growth capture earlier theorists envisioned. Mullin shows, instead, that capture by anti-growth or pro-environmental interest groups is common among special water districts.

ter consumption through demand-side management. Yet, we have very little information on which strategies worked best to change behavior and increase water conservation across California's districts or across the Western United States more broadly (Inman and Jeffrey, 2006; Stritch, 2017). Previous work has examined how individual demographic factors and different appliances predict water consumption (Gleick et al., 2003; Peters et al., 2011; Willis et al., 2011, 2013) and which factors drive urban water management changes (Hughes et al., 2013), but less work has examined the role of water district policy in driving water conservation. As John Fleck noted in an interview with Vox, the Western US has managed to conserve far more water through residential demand side management than expected, but "no one fully understands how we did it" (Plumer and Fleck, 2016). Clearly, there is a need for research to evaluate how this water conservation was achieved. [5]

This research aims to evaluate which policies have proven most effective at driving water conservation. In this project, we evaluate the effectiveness of a number of strategies: pricing, social norms and penalties. First, we might expect that increasing the cost of water might change behavior, given existing research on water and energy conservation (Heberlein and Warriner, 1983; Olmstead and Stavins, 2009; Steg, 2008). Increasing costs, may be particularly appealing because it is an inexpensive strategy that can apply to all households (Campbell et al., 2004). In the California case, multiple strategies have been used to increase the cost, including drought surcharges, increases in the average price for a water bill ($/15 CCF plus a periodic service charge), and changes in the pricing structure (uniform vs. tiered rates). Apart from cost increases, we might expect subsidies for long-term changes, like replacing lawns or appliances, might decrease consumption. In existing energy and water conservation research, subsidies have been shown to lead to increases in conservation investments (Hassett and Metcalf, 1995; Martínez-Espiñeira et al., 2014; Timilsina et al., 2012). In this project, we examine each of these policies, from cost increases to rebates, to see whether

[5] Evidence from water conservation efforts in New South Wales — Australia's most populous state which shares many socioeconomic traits with California — indicates that conservation in such a setting is possible using outdoor water restrictions, low flush toilets, and higher water rates (Cahill et al., 2013).

they predict overall aggregate water conservation across and within urban water districts.

Second, messaging strategies may be effective at driving conservation. Significant psychology and public policy research suggests that social norms messaging strategies can effectively change conservation behavior (Allcott, 2011; Jorgensen et al., 2009; Mildenberger et al., 2013). By contrast, we also know that simple information may fail to change conservation (Fielding et al., 2013; Mildenberger et al., 2013). Providing feedback, both on individual behavior and on neighbors' behavior, can be quite effective at changing behavior (Abrahamse et al., 2005, 2007). We collected data on how water districts communicated with customers. We examine whether they provided information on the drought or water conservation strategies. We also examine whether and when districts started providing personalized feedback information on year over year conservation, or social comparison information with a given customer's use being compared to others in the community. Several districts use this neighbor comparison strategy, which is widely adopted in energy conservation campaigns, but less common for water conservation.

Third, we might expect penalties to change behavior, and many districts used this strategy. Past research shows that, at least for corporate actors, penalties can be effective at preventing and deterring violations (Shimshack and Ward, 2005; Shimshack, 2014). Here, we examine the use of penalties, collecting data on whether or not monetary or public penalties were issued, and if so how many over time. In addition to these policy levers, in future iterations, we will also examine whether drought severity affected water conservation, and collect other covariate information about the water districts such as monthly rainfall and census data.

This research aims to provide insight into which policies are working to drive water conservation in California. Understanding the most effective water conservation strategies has clear benefits. If some water districts are proving more successful at creating behavior change, it would be useful to understand why so that state policy can encourage other districts to adopt a similar approach. Without high quality evidence-based policy evaluation, it will be difficult to propose the most effective policies to continue to save water in California—a critical task given climate models predict increase drought Cook et al. (2015); Diffenbaugh et al. (2015); Williams et al. (2015). More broadly, this research contributes to the debate over the effectiveness of specialized governance as an institutional solution to public goods provision. Understanding both how and why Californian urban water districts responded to the five-year drought and subsequent water conservation targets may augment our understanding of special district governance as a whole.

Data & Research Design

This study uses an original monthly panel data set of California urban water district's conservation policies between June 2014 and March 2016. Overall, there are 411 urban water districts in California. We first directly contacted all water districts using a questionnaire to collect monthly data. We asked districts about their use of pricing, messaging, and penalties. We also asked water district employees which conservation measures they thought were most effective. We later contacted districts a second and third time using a shortened questionnaire to improve response rates.

For pricing data, we asked water districts to tell us about how they charged residential customers for water each month in a number of ways: the average price per 1 CCF of water used and the price per 15 CCF of residential water use. Given that water bills can be tiered, in that they rise as consumption increases, we wanted to get a sense of both the marginal cost for the first CCF of water consumed, as well as the total costs if a customer consumed an average amount of water, which we set at 15 CCF. When this data was not available or district representatives did not provide it directly, we utilized water-pricing schedules to calculate pricing information for 15 CCF of residential use following a standardized methodology.[6] We

[6]For tiered pricing-structures, we calculated the price per tier per CCF and summed across tier, adding applicable charges and taxes. For uniform pricing structures, we simply multiplied the price for a single CCF by fifteen. In four districts, pricing data per single CCF was available, but rate structures were not specified or available. For these cases, we multiplied the price per single CCF by the mean of the ratio between the

also asked water districts to tell report their total revenue by month from residential usage. If no other data was available, we used this data to estimate both the cost per 1 CCF and 15 CCF by dividing the total residential revenue by the total amount of residential water sold in that month.[7]

We also asked districts about other monetary incentives they used to induce conservation, including rebate programs and drought surcharges. Each of these measures were coded as a binary variable. On rebates, districts were asked if they offered a conservation rebate program. If a program was provided, then districts were additionally asked for the program's monthly budget as an approximation of the program's scope. Some districts chose to adopt monetary drought surcharges during this time period to induce water conservation.

We also asked districts if they were relying on a number of informational and social norms messaging strategies: the basic provision of information regarding the drought or water conservation strategies; feedback on individual water usage; comparison to neighbors' or average district water usage. We also asked about a number of penalties, including social penalties; warnings and citations; monetary penalties; and required reductions in watering days per week. Monetary penalties included actions such as issuing overuse citations/fees via a user's water-bill. Typically, these fines increased with each use-violation.[8] Information provision, individualized feedback, neighbor comparison, social penalties and monetary penalties were coded as binary variables. Additionally, we collected monthly data from the SWRCB on the number of citations and/or warnings districts issued and the number of watering days districts reduced per week.

Of the total population of urban water districts in California, approximately 28% percent responded to our initial requests with some information. We recognize that districts which chose to respond to our questions could have higher capacity to implement water

price per 15 CCF and 1 CCF (21) to approximate price per 15 CCF based on our existing data.

[7]This compares well with data where we have both the direct 1 CCF and 15 CCF variables as well as the total revenue.

[8]From South Tahoe Public Utility District: "First violation written warning; second is $100 fine; third $250; fourth $500 [and] may discontinue water usage."

conservation strategies and conserve water; for this reason, our sample may not be representative of all Californian water districts. That said, conservation performance is similar among responsive and non-responsive districts. The mean value for our primary dependent variable—percentage point difference from conservation tier targets—is 6.2 p.p. for districts in-sample and 5.4 p.p. for districts out-of-sample. Thus, our in sample districts on average performed slightly *worse* than the overall population. We take this to suggest that the sample is fairly representative in terms of conservation performance among all Californian urban water suppliers.

To estimate the efficacy of these water conservation strategies, we constructed a series of dependent variables using primary data from the California SWRCB.[9] We rely on three measures from the SWRCB data: the calculated total monthly potable water production for years 2014-2016 (monthly use); the calculated total monthly potable water production for year 2013 (baseline use); and the reported gallons-per-capita-day of residential use (residential use).[10] The second measure—monthly production for 2013—serves as the baseline quantity to which all state-implemented conservation standards refer. Thus, water districts' conservation performance is evaluated based on a designated percent-reduction in monthly water production as compared to the 2013 baseline production. Using these variables, we compared each month's water consumption to the water consumption in that month during the 2013 baseline. In addition, to examine districts ability to meet the tiered targets, we constructed an additional dependent variable measuring the percentage point difference between the percent monthly reduction in water consumption compared to each mandated conservation target.[11]

[9] The SWRCB dataset is available online and contains water-production rates spanning our panel data's sampling period. This dataset also includes estimates of total population served per month, water days allowed per week, and citations issued per month. We use each of these to later to approximate missing data-points in the panel data.

[10] As is noted in the original data set, SWRCB staff calculated the first two measures, whereas water-district representatives were responsible for providing the third.

[11] For the first twelve months of the test period, all districts sought to reduce monthly water production by 20 percent of production for the correlative month in 2013. The percent reduction in monthly reduction relative to the 2013 baseline was subtracted from the 2013 baseline production, yielding a percentage point difference measuring the extent to which water districts met or failed to meet specific conservation targets.

We constructed an additional dependent variables measuring the quantity of monthly conservation per district. Ideally, this unit-savings dependent variable would be measured in 15 CCFs, allowing us to frame monthly conservation in terms of the number of households "disconnected" from the water-supply grid.[12] We assume that single-family households consist of four people, and use SWRCB data on population served per district to construct the unit-savings dependent variable.

The following analysis tests the hypothesized effects of pricing, messaging and penalties on water-conservation. We rely on fixed effects estimators to control for the time-invariant characteristics of Californian water-use districts. We compute a number of models, each including a specific water conservation strategy, district and time-period fixed effects for each month of the test-period. The basic model is specified as follows:

$$Y_{it} = \alpha_0 + \gamma_i + \delta_t + \alpha D_{it} + \beta X_{it} + \epsilon_{it} \tag{1}$$

where Y_{it} is our water conservation dependent variable, compliance with the tiers; α_0 is the intercept; γ_i is the water district fixed effect; δ_t is the month fixed effect; αD_{it} is the relevant conservation strategy being examined in a given model; and βX_{it} are control covariates.

Results

Using tier performance as the dependent variable, we assessed conservation performance for the population of urban water suppliers in the SWRCB database. During the period of analysis, more than 99 percent of urban water districts conserved water relative to their 2013 monthly baselines, on average. In fact, only three districts—the cities of California

A binary variable indicating whether or not districts met monthly targets was also constructed based on this percentage point difference. Districts with a percentage point difference less than or equal to zero were assigned scores of one, indicating that they had met or surpassed their monthly conservation target. Conversely, differences greater than zero were assigned scores of 0, indicating a failure to meet a monthly conservation target.

[12]Fifteen CCF is the average monthly single family-household water consumption in California from 2005 to 2010 (DeOreo et al., 2011).

City and El Segundo, and the Humboldt Bay Municipal Water District—increased average monthly water production from their baseline. One hundred districts met or exceeded the 2013 water conservation target of 20 percent over the test period. On average, water districts exceeded their revised tiered conservation targets by five percentage points—approximately thirty-three million gallons of water production per month. Overall, slightly more than a quarter of districts met the updated 2015 conservation targets (see Table 1). More than fifty percent of districts exceeded their assigned conservation targets by an average of 6.1 percentage points (or 13.9 million gallons) per month. In two instances, district water-usage overran monthly conservation targets by more than 100 percentage points.[13] Overall, there was a wide range in districts' performance relative to the 20% target and their updated tier targets (Table 1). On a monthly basis, some districts outperformed their targets by a few p.p., while many others often missed their targets by 14 p.p. or more.

Table 1: Distribution of Dependent Variable (in Panel)

Variable	Measure	Min	Q1	Mean	Q3	Max
Y_{1i}	P.p. Savings off Tier *(percentage points)*	-66.05	-3.39	5.41	14.18	128.42
Y_{2i}	District Per Capita Use *(15 CCF/capita)*	0.00	0.25	0.78	0.48	182.93
Y_{3i}	Districts Use off Tier *(15 CCF)*	-338978.42	-6902.94	-6599.67	-784.13	31830.05

We asked water districts which conservation strategies they thought were most effective. When reviewing these responses, two general themes emerge. First, many districts discussed all three strategies as being important. In fact, surprisingly few districts reported pricing or penalties alone—particularly monetary fines—to be effective. When monetary penalties were preferred, districts seemed to view social and monetary penalties as mutually-beneficial. Districts commonly responded that inundating consumers with information about individual and communal water use, as well as drought conditions, would incentivize conservation. A number of responses implied that water district employees believed that the direct and

[13]See: Casitas Municipal Water District (Mar-2015) and City of Pico Rivera (Mar-2016).

personalized provision of information would intrinsically motivate Californians to be more prudent in their water usage. Restrictive strategies, such as limiting the number of weekly water days or increasing usage-rates, were typically reserved for instances where motivational strategies proved insufficient.

Table 2: 30 Best and Worst Performing Districts in California (average tier performance)

District	Y_{1i}	tier
Cambria Community Services District	-21.75	2
Montecito Water District	-19.26	8
Bella Vista Water District	-18.94	9
Brawley City of	-18.76	8
Dublin San Ramon Services District	-13.84	3
California Water Service Company Livermore	-12.46	6
Benicia City of	-12.25	5
Santa Barbara City of	-11.59	3
Soquel Creek Water District	-10.73	2
Pleasanton City of	-10.61	6
Santa Cruz City of	-10.07	2
California Water Service Company Redwood Valley	-9.59	4
Menlo Park City of	-8.95	4
Livermore City of Division of Water Resources	-7.72	5
California-American Water Company Sacramento District	-6.37	5
San Dieguito Water District	15.38	7
Livingston City of	15.68	8
Yucaipa Valley Water District	15.71	9
Lee Lake Water District	15.79	8
Hesperia Water District City of	16.16	8
Hawthorne City of	16.48	4
Elsinore Valley Municipal Water District	16.56	7
Beaumont-Cherry Valley Water District	16.73	9
Calexico City of	17.02	5
La Habra City of Public Works	17.14	7
Crescent City City of	17.36	4
Los Angeles County Public Works Waterworks District 29	17.50	9
Blythe City of	17.87	8
Phelan Pinon Hills Community Services District	18.57	8
California City City of	27.98	9

Table 2 shows the best and worst performing districts in California in terms of how they met the initial 20% reduction target and their later tier target on average. When the dependent variable is zero, the district has met their target; thus, more negative number show over performance, and more positive numbers show under performance. For example, the best performing district, Cambria Community Services District, had an initial target of reducing their water use by 20% compared to 2013. When the targets were updated, they were placed in the relatively modest Tier 2, and had to achieve 8% reductions. Ultimately, Cambria managed to beat these targets, on average, by 26 p.p. per month. Three of the five top performers, which each saved 19% or more, are located along the coast in Southern California, where the drought was particularly severe and long lasting.[14] By contrast, many of the worst performing districts are located inland.

Table 3: Conservation Strategies - Percent Implementation in Top/Bottom Quartiles

Strategy	Best Performing (%)	Worst Performing (%)
Info, Tips, and Tricks	96	100
Drought Info	96	89
Rebate Program	88	74
Pricing Structure	78	67
Personal Feedback	76	74
Monetary Penalties	64	79
Social Penalties	40	18
Drought Surcharge	32	29
Neighbor Comparison	26	11

We examined cross-sectionally which strategies were more likely to be used by 1) the 30 best and worst performing districts and 2) districts falling the top and bottom quartiles of conservation performance. Separating our sample districts into quartiles based on conservation performance reveals some differences in policies that may be driving observed district performance (Table 3).[15] Common strategies used in a majority of districts in both the highest and lowest quartiles include basic information, drought information, personal feedback, tiered pricing, and monetary penalties. While rebate programs were also very common, they were used 25% more often by the best performing districts than the worst.

[14] Cambria Community Services District, Montecito Water District, City of Grover Beach

[15] There is significant missingness in the data; we only have data on around a third of the top and bottom quartiles.

However, districts in the best- and worst-performing quartiles are distinct on a number of measures, perhaps explaining the divergence in conservation performance over the period of analysis. The highest-performing districts were larger—serving 51,900 customers on average compared to 42,123 for the worst performing districts. Districts in the best-performing quartile were almost two-times more likely to use social penalties than the worst performing districts. In addition, one in four of the best-performing districts provided feedback on how households were performing in comparison to their neighbors; only one in ten of the worst performing districts provided similar information.

There were also stark differences in the average number of warnings and citations issued per month. On average, districts in the top quartile of conservation performance issued more than four-times the warnings and citations per month (54) than did districts in the lowest-performing quartile (13). This difference persists even when controlling for population. Per month, districts in the best-performing quartile issued nine citations and warnings for every 10,000 customers. Districts in the worst-performing quartile issued only two warnings and citations per 10000 customers per month.

Table 4: Average Bill Pricing (15 CCF Use + Service Charge)

Districts	Min	Q1	Mean	Q3	Max
Best Performers	50.38	69.11	92.20	116.68	131.26
Worst Performers	32.41	36.38	42.32	49.10	50.72

Table 5: Average Price per CCF Use

Districts	Min	Q1	Mean	Q3	Max
Best Performers	3.02	3.86	6.85	9.41	11.54
Worst Performers	1.00	1.57	2.15	2.26	4.27

There are also notable differences in the average bill price and average price per unit use in the best and worst performing districts (Table 4, Table 5). Overall, the best performers charge around 45% more on average for 15 CCF of water than the worse performers. Figure 1 displays the change in estimated water bill prices and water use among all districts. This figure suggests that while water bills in the best-performing districts were higher than water bill in the worst-performing districts, the relative change in bill price over the study period does not appear to vary significantly between districts in each performance quartile. Moreover, Figure 1 provides preliminary evidence that there is no immediate relationship between bill-pricing and water use. We see that water use counter-intuitively increases from July-2015 to March-2016 despite concurrent increases in bill-pricing across all districts.

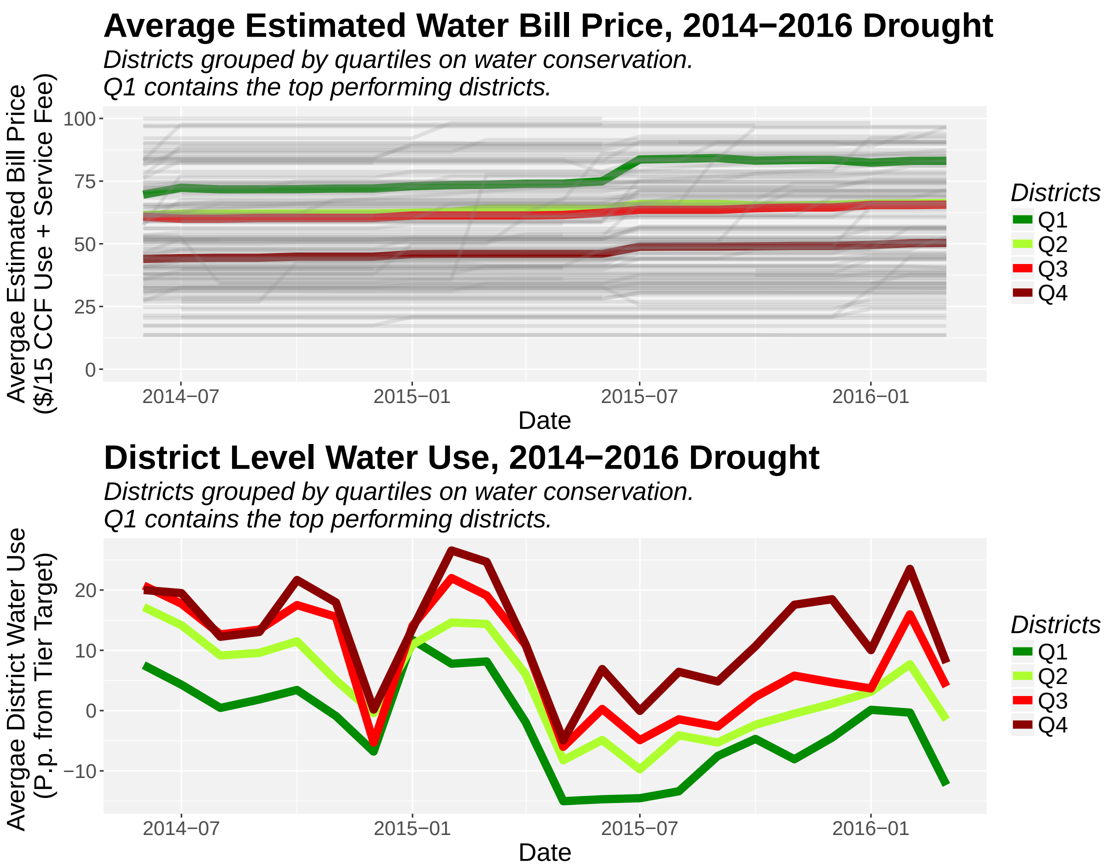

Figure 1: *Average estimated water bill price and water use among all districts.* Bill price is displayed in the top pane, while the bottom pane visualizes water use. Faded grey lines in the top pane represent the change in estimated bill price for individual districts across the study period.

Next, we ran fixed effects models to examine whether various conservation strategies supported districts' efforts to meet their conservation targets. These models include both district and month fixed effects and control for monthly rainfall and drought severity. One major limitation with our preliminary results is the small number of districts that adopted

Table 6: Estimated Effects of Conservation Strategies on Meeting Water Reduction Targets

	Estimate	Std. Error	p-value	N
Pricing				
Average bill price ($/15 HCF)	−0.07	0.12	0.56	108
Rebate Program	−2.91	2.56	0.25	101
Drought Surcharge	−1.87	1.85	0.31	97
Messaging				
Info, Tips, Tricks	+2.68	1.83	0.14	94
Drought Information	+0.90	1.42	0.53	93
Personal Feedback	−1.91	2.11	0.37	82
Neighbor Comparison Feedback	+0.84	1.71	0.62	97
Penalties				
Social Penalty	−5.91	1.71	0.00	94
Monetary Penalty	+0.23	1.42	0.87	97
Water Days per Week Reduction	−0.21	0.18	0.25	334

District and month fixed effects.

Controlling for district-level drought severity and precipitation.

Robust standard errors, clustered at district level.

some of these policies during this time period.[16] Fixed effects models identify their effects based on the units that change their status. When not enough units switch to using or stop using a given strategy, the standard errors on the estimate will be biased downwards.[17] Consequently, our results should only be treated as preliminary at this point.

Nevertheless, in terms of evaluating water conservation policies' effectiveness, these preliminary results provide some evidence. Table 6 shows the estimated effects of pricing, messaging and penalty strategies. Overall, we find that only one strategy effectively incents water conservation: social penalties. Districts adopting social penalties, on average, are 5.9 p.p. closer to meeting their targets.

[16]In our current data: drought surcharge (9 switch); rebate program (3 switch); drought information (9 switch); information tips and tricks (6 switch); neighbor comparison (10 switch); personal feedback (13 switch); social penalties (8 switch); monetary penalties (17 switch).

[17]One solution is to create non-parametric standard errors. If we are not able to collect more data, we will take this approach. Another solution is to impute missing data, although for binary treatment variables this may present some problems.

Interestingly, we also find that neither messaging strategies nor pricing strategies reduce water consumption. Distributing information on drought severity, conservation strategies, or personal/neighbor water-use rates does not appear to affect conservation. Similarly, implementing rebate programs or increasing the price of water use fails to produce any effect on water conservation at the conventional level of statistical significance. The null results on pricing confirm the intuition laid out in Figure 1 and broadly indicates that water consumption may be price inelastic.

In future analyses, we will examine whether lagging the independent variables changes the results, since we may not expect that people respond immediately to these strategies. We may also try collapsing the panel down to yearly increments, since the SWRCB assessed individual districts conservation performance cumulatively from June 2015 onward. Finally, we aim to collect more data overall to try to improve our fixed effects estimates.

Conclusion

Despite the historic nature of California's most recent drought, and the recognition that drought will become more severe in the state over time with climate change, California's policy framework for urban water conservation is inadequate. There is no standardization across the state in terms of data reporting for policy implementation or water prices. From the data we were able to gather, there are large inequalities in citizens' cost of water: comparing the price per 15 CCF in the first quartile to the third quartile, residents pay almost three times as much for water (Table 4). And this estimate does not even include the least expensive and most expensive districts. There are also large differences in districts use of strategies to try to change behavior, most notably the most effective strategies: rebates and social penalties.

In May 2016, once the drought began to lessen in Northern California, the Governor lifted the mandatory tiers. By that time, water districts cumulatively had saved 24% between June

2015 and March 2016, just missing the 25% target. Still, the Governor required urban water districts to continue reporting monthly to the State Water Board. The state would likely benefit from gathering more comprehensive data from water districts, as is common practice for utilities in the electricity sector. Important variables include the cost for an average bill (15 CCF could be used as a benchmark) and what policies the district is using to try to save water. The SWRCB could also play a more active role in trying to disseminate strategies that seem effective, potentially helping to fill some capacity problems arising from decentralized governance.

Overall, our findings provide evidence that decentralized water governance may significantly hamper a state's ability to address water scarcity. While some districts with high capacity or facing significant water shortages may adopt a creative or 'all of the above' strategy to drive conservation, other districts may lag in their efforts. Without centralized reporting and accountability, we should not expect long term success for water conservation in California.

References

Abrahamse, W., L. Steg, C. Vlek, and T. Rothengatter (2005). A review of intervention studies aimed at household energy conservation.

Abrahamse, W., L. Steg, C. Vlek, and T. Rothengatter (2007, 12). The effect of tailored information, goal setting, and tailored feedback on household energy use, energy-related behaviors, and behavioral antecedents. *Journal of Environmental Psychology 27*(4), 265–276.

Allcott, H. (2011). Social norms and energy conservation. *Journal of Public Economics*.

Axelrod, R. and R. O. Keohane (1986). Achieving Cooperation under Anarchy: Strategies and Institutions. In K. A. Oye (Ed.), *Cooperation under anarchy*, pp. 226–254. New York: Princeton University Press.

Bollens, J. C. (1957). *Special District Governments in the United States*. Berkeley: University of California Press.

Brown, E. G. (2015). Executive Order B-29-15.

Cahill, R., A. M. Asce, J. Lund, and M. Asce (2013). Residential Water Conservation in Australia and California. *Journal of Water Resources Planning and Management 139*, 117–121.

Campbell, H. E., R. M. Johnson, and E. H. Larson (2004). Prices, devices, people, or rules: The relative effectiveness of policy instruments in water conservation. *Review of Policy Research*.

Cook, B. I., T. R. Ault, and J. E. Smerdon (2015). Unprecedented 21st century drought risk in the American Southwest and Central Plains. *Science Advances 1*(1), e1400082.

DeOreo, W. B., P. W. Mayer, L. Martien, M. Hayden, A. Funk, M. Kramer-Duffield, and R. Davis (2011). California Single Family Water Use Efficiency Study. Technical report, Aquacraft, Boulder.

Diffenbaugh, N. S., D. L. Swain, and D. Touma (2015). Anthropogenic warming has increased drought risk in California. *Proceedings of the National Academy of Sciences 112*(13), 3931–3936.

Fielding, K. S., A. Spinks, S. Russell, R. McCrea, R. Stewart, and J. Gardner (2013). An experimental test of voluntary strategies to promote urban water demand management. *Journal of Environmental Management*.

Gleick, P. (2002). Soft Water Paths. *Nature 418*, 373.

Gleick, P. (2003). Global Freshwater Resources: Soft-Path Solutions for the 21st Century. *Science 302*(5650).

Gleick, P. H., D. Haasz, C. Henges-Jeck, V. Srinivasan, G. Wolff, K. Kao Cushing, and A. Mann (2003). *Waste Not, Want Not: The Potential for Urban Water Conservation in California*. Number November.

Hassett, K. A. and G. E. Metcalf (1995). Energy tax credits and residential conservation investment: Evidence from panel data. *Journal of Public Economics 57*(2), 201–217.

Heberlein, T. A. and G. K. Warriner (1983). The Influence of Price and Attitude on Shifting Residential Electricity Consumption from On- to Off-Peak Periods. *Journal of Economic Psychology 4*, 107–130.

Hughes, S. (2012). Voluntary Environmental Programs in the Public Sector: Evaluating an Urban Water Conservation Program in California. *Policy Studies Journal*.

Hughes, S., S. Pincetl, and C. Boone (2013). Triple exposure: Regulatory, climatic, and political drivers of water management changes in the city of Los Angeles. *Cities 32*, 51–59.

Inman, D. and P. Jeffrey (2006). A review of residential water conservation tool performance and influences on implementation effectiveness. *Urban Water Journal 3*(3), 127–143.

Jorgensen, B., M. Graymore, and K. O'Toole (2009). Household water use behavior: An integrated model. *Journal of Environmental Management*.

Martínez-Espiñeira, R., M. A. García-Valiñas, and C. Nauges (2014). Households' pro-environmental habits and investments in water and energy consumption: Determinants and relationships. *Journal of Environmental Management 133*, 174–183.

Mildenberger, M., L. Stokes, B. Savan, B. Kolenda, and D. Dolderman (2013). Beyond the Information Campaign: Community-Based Energy Behavioral Change at the University of Toronto. *Environmental Practice 15*(2), 147–155.

Mullin, M. (2009). *Governing the Tap: Special District Governance and the New Local Politics of Water*. Cambridge: The MIT Press.

Olmstead, S. M. and R. N. Stavins (2009). Comparing price and nonprice approaches to urban water conservation. *Water Resources Research 45*(4), W04301.

Ostrom, E. (1972). Metropolitan Reform: Propositions Derived from Two Traditions. *Social Science Quarterly 53*, 474–493.

Ostrom, E. (1990). *Governing the commons: the evolution of institutions for collective action*. Cambridge: Cambridge University Press.

Ostrom, V., R. Bish, and E. Ostrom (1988). *Local Government in the United States*. San Fransisco: ICS Press.

Ostrom, V., C. M. Tiebout, and R. Warren (1961). The Organization of Government in Metropolitan Areas: A Theoretical Inquiry. *American Political Science Review 55*, 831–842.

Palazzo, J., O. R. Liu, T. Stillinger, R. Song, Y. Wang, E. Hiroyasu, J. Zenteno, S. Anderson, and C. Tague (2017). Urban Responses to Restrictive Conservation Policy During Drought. *Water Resources Research*.

Peters, G. P., G. Marland, C. Le Quéré, T. Boden, J. G. Canadell, and M. R. Raupach (2011, 12). Rapid growth in CO2 emissions after the 20082009 global financial crisis. *Nature Climate Change 1*, 2009–2011.

Plumer, B. and J. Fleck (2016, 9). The media loves doomsday stories about the Wests water crisis. Heres what they miss.

Shimshack, J. P. (2014). The Economics of Environmental Monitoring and Enforcement. *Annual Review of Resource Economics 6*(1), 339–360.

Shimshack, J. P. and M. B. Ward (2005). Regulator reputation, enforcement, and environmental compliance. *Journal of Environmental Economics and Management 50*(3), 519–540.

Steg, L. (2008). Promoting household energy conservation. *Energy Policy 36*(12), 4449–4453.

Stritch, J. M. (2017). Minding the Time: A Critical Look at Longitudinal Design and Data Analysis in Quantitative Public Management Research. *Review of Public Personnel Administration*, 1–26.

SWRCB (2015). State Water Resources Control Board Resolution No. 2015-0032 To Adopt an Emergency Regulation for Statewide Urban Water Conservation.

Timilsina, G. R., L. Kurdgelashvili, and P. A. Narbel (2012). Solar energy: Markets, economics and policies. *Renewable and Sustainable Energy Reviews*.

Williams, A. P., R. Seager, J. T. Abatzoglou, B. I. Cook, J. E. Smerdon, and E. R. Cook (2015). Contribution of anthropogenic warming to California drought during 20122014. *Geophysical Research Letters 42*(15), 6819–6828.

Willis, R. M., R. A. Stewart, and D. P. Giurco (2013). End use water consumption in households: impact of socio-demographic factors and ef fi cient devices. *Journal of Cleaner Production 60*, 107–115.

Willis, R. M., R. A. Stewart, K. Panuwatwanich, P. R. Williams, and A. L. Hollingsworth (2011). Quantifying the influence of environmental and water conservation attitudes on household end use water consumption. *Journal of environmental management 92*(8), 1996–2009.