Heterogenous effects of housing lot size composition on average single-family household water consumption – evidence from water agency level data in California

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Abstract

Various studies have pointed out that the type of housing development projected to occur in California might have significant impacts on aggregate residential water demand. Specifically, much of California's new housing stock is located inland on larger lots situated in increasingly hotter and drier regions. In this paper, we seek to answer the question, "How has recent housing development in California affected residential water consumption?". By utilizing a unique panel dataset of single-family residential monthly water use and lot size composition for water agencies in California, we estimate a water demand equation and identify the impact of lot size on residential water consumption. Further, we provide preliminary evidence on whether contemporaneous conservation policies have been able to attenuate the effects of new housing developments on residential water use. Our estimation results suggest that average monthly single-family household water usage is higher in water agencies with a higher share of houses with large lot sizes. These water agencies are generally more responsive to price changes than water agencies with a higher share of small lots. However, the exact pattern varies by region, which suggests that local factors such as regional climate, population density and the types of water usage are important determinants of water demand. In identifying the relationship between lot size composition and water use, our paper provides important policy insights into the dynamics of water use across water agencies and regions with different structural characteristics. Our findings not only inform the development of targeted water conservation strategies but also underscore the importance of regional specificity in policy design.

Keywords: residential water demand; drought; lot size; water conservation.

JEL codes: C23, Q25, Q54

1. Introduction

Water scarcity is increasingly becoming a major problem in many parts of the world, compounded by the rise in extreme weather events like droughts (Hanjra, M., & Qureshi, M., 2010; Schewe, J., et. al., 2014). Effective water management has thus become an important policy issue. In the U.S., California presents an interesting case study for these challenges because not only is it one of the most populated regions, but it is also one of the driest. The state relies heavily on precipitation and snowpacks for water (Carle, D., 2015), and is becoming increasingly vulnerable to the impacts of climate change (Gonzales & Ajami, 2017).

Additionally, demographic shifts are affecting California's water use. Over the next 25 years, the state's population is projected to grow by about 15%, mostly in drier and hotter inland regions (Johnson et al., 2022). This is especially concerning because water usage correlates positively with temperature and negatively with precipitation (Brelsford et al., 2017; Solimon, 2021; El-Khattabi et al., 2022). Moreover, outdoor water use, which makes up 50% of total water demand in arid regions, is likely to increase (Wentz and Gober, 2007; Balling et al., 2008).

Given the growing population and the exacerbating climate change conditions, understanding the factors that influence residential water demand becomes important because it represents a major portion of the overall water use in California (Renwick and Green, 2000). While there are several structural and demographic factors that may influence water use, the primary focus of this paper is on lot-size. Water usage in households with larger lots typically involves a discretionary use in the form of outdoor use for landscaping. Unlike indoor water use, which mostly pertains to basic needs such as drinking and sanitation and can be very difficult to reduce (Renwick and Green, 2000), outdoor water use is arguably relatively easier to reduce (Inman, D., & Jeffrey, P., 2006; Mansur and Olmstead, 2012).

Unlike previous studies that mainly consider spatial variations in lot size, our contribution lies in examining temporal changes in housing development and composition across water agencies. The main question this paper aims to answer is, "How has recent housing development and composition in California affected residential water demand?" Further, we plan to investigate how climatic variables like temperature and precipitation, as well as conservation policies, condition the impact of lot size on water use.

By answering these questions, we hope to offer valuable insights to policymakers for effective planning against future water scarcity. The rest of the paper is organized as follows: Section 2 reviews relevant literature, Section 3 describes the research setting, Section 4 presents the theoretical framework, Section 5 provides data description, Section 6 outlines the empirical methods, Section 7 presents the main estimation results, Section 8 offers additional evidence regarding lot size and conservation, and Section 9 concludes the paper.

2. Literature Review

There have been numerous studies identifying the key factors that determine residential household water demand, such as pricing (El-Khattabi et. al, 2021; Marzano et al., 2020), income (Arbues et al., 2003), household size (Suarez-Varela, 2020), weather (Renwick & Green, 1999) and public awareness campaigns (Kenney et. al., 2008). This identification is important because effective water demand management policies play a critical role in reducing water usage (Hewitt and Hanemann, 1995; Renwick and Green, 1999).

One research area that has gained attention is the relationship between housing characteristics and water use. (Hanak & Davis, 2006) explored the association between lot-size and water use and found that larger lots tend to be associated with higher water consumption due to increased outdoor water, such as landscaping and swimming pools. Similarly, (Renwick & Green, 1999) found that lower-income households have a higher price elasticity of water demand compared to households with low income. More recently, (El-Khattabi et. al., 2021) have showed that households with higher baseline water usage tend to be more responsive to water prices than those with lower baseline use. They also found that wealth plays a key role in driving households' water demand. The type of water use has also been shown to play a key role in determining water demand. For example, (Rawls et. al., 2010) concluded that households reduce their outdoor water use first when their water consumption is separated into outdoor and indoor use.

Empirical studies make the case that differences in water usage across different regions may be caused by structural differences such as housing lot size (Lee & Tanverakul, 2015). This paper extends this research on water use to better understand the nuances of how housing lot size composition influences water use across single-family households in water agencies across regions. Results of this study will shed light on the effectiveness of water conservation policies and contribute to achieving efficiency in water use in California.

3. Research Setting

California, a state that has seen severe droughts in recent years, serves as the setting for this paper. The scarcity of water in California, especially during droughts, necessitates prioritizing its allocation for essential uses such as drinking and sanitation, over discretionary uses like landscaping and other outdoor residential water use.

Our research focuses in on single-family residential households in California because residential water sector is considered to have a lower economic value compared to other sectors and is often the first target for water conservation efforts (Mansur and Olmstead, 2012). With population growth, the number of single-family households in California has increased, with many of these new residential households located inland in central California. These houses tend to have larger median lot sizes, especially those in drier and hotter regions (see Table 1[1]).

Evidence in literature suggests that outdoor water uses account for more than two-thirds of total water consumption in single-family residential households (Guhathakurta & Gober, 2010). Therefore, water agencies with a higher proportion of larger lots are likely to consume more water but also offer greater potential for water conservation, primarily because outdoor water use is discretionary and can be relatively easier to reduce compared to indoor water use.

Figure 1 illustrates the variation in water use in California by lot size groups[2]. Interestingly, it reveals a recurring pattern - whenever water use declines, the percentage reduction in consumption is consistently higher for larger lots compared to smaller lots. This trend suggests that in periods of decreased water use, households with larger lots have a greater capacity to reduce their consumption, presumably due to the discretionary nature of their outdoor water use.

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[1] Figures A1-A2 in the appendix show trends in median lot size across regions in California (Source: Tax assessor data)

[2] We classify residential lots into two categories, 'large' and 'small', based on the shares of houses in the lower or upper quartiles of lot size in California. See the empirical methods section for detailed specifications of these categories. 2003 is the earliest year for which both lot size and water data are available, so it is chosen as a base year for the percentage change calculation for the graph.

4. Theoretical Framework

According to economic theory, households optimize their water consumption to maximize utility, given their budget constraint.

The utility function U for a representative household can be expressed as:

$$U = U(X, W(L, Z))$$

where X represents the consumption of all other goods, and $W(L, Z)$ represents water use by the household as a function of lot size (L), and a composite of variables represented by (Z) likely to influence water demand by the household, and of the form:

$$W(L, Z) = \alpha L^{\beta} + \gamma Z$$

where $\alpha > 0$, $\beta > 0$, and γ is a coefficient capturing the linear effect of Z.

The representative household's budget constraint is given by:

$$Y = (P_X \times X) + (P_W \times W(L, Z))$$

where Y is the household's income, P_X is the price index for all other goods, X is the amount of all other goods, and P_W is the price of water.

Substituting $W(L, Z) = \alpha L^{\beta} + \gamma Z$ into the budget constraint, we have:

$$Y = (P_X \times X) + (P_W \times (\alpha L^{\beta} + \gamma Z))$$

The Lagrangian L can be written as:

$$\mathcal{L} = U(X, \alpha L^{\beta} + \gamma Z) + \lambda \left(Y - (P_X \times X + P_W \times (\alpha L^{\beta} + \gamma Z))\right)$$

The first-order condition (F.O.C) with respect to lot size L is:

$$\frac{\partial \mathcal{L}}{\partial L} = \frac{\partial U}{\partial W} \times \frac{\partial W(L, Z)}{\partial L} - \lambda \beta \alpha L^{\beta - 1} P_W = 0$$

Solving the F.O.C will give the optimal value of L that maximizes U for the representative household. Given our assumption about $W(L, Z) = \alpha L^{\beta} + \gamma Z$, water demand W is positively related to L and influenced by Z. Holding Z constant, an increase in lot size L is expected to increase water usage W.

5. Data

We use data from several sources in this paper (see Table 2 for a list of definitions of the variables included in this paper). Water use data comes from about 400 water agencies in California that are required to report average monthly gallons per capita per day (GPCD) to the California State Water Resources Control Board (SWRCB), and the Department of Water Resources (DWR). This is combined with monthly weather data for each water agency using the Parameter-elevation Relationships on Independent Slopes Model (PRISM) (Daly et. al, 2008) that reports daily gridded data for precipitation and temperature across the United States. Price data are collected from a price survey of 189 water agencies[3] in California from years 2003 to 2019, so the final analysis is limited to these agencies and the time period 2003 to 2019[4]. We include data on house-level characteristics from the tax assessor survey for each household, aggregated to the water agency level (to protect customer privacy and match the spatial extent of our dependent variable) for variables such as lot size, house assessed value, year built, number of rooms and bathrooms, if there is a pool in the house and ownership status. Lastly, we segregate each water agency into different regions based on similar climatic and hydrologic conditions.

Table 3 presents summary statistics for selected variables across different regions in California, highlighting variations in water usage, climate, and housing characteristics. Inland, dry, and hot regions such as the Central and Desert regions show the highest average water consumption, indicative of the inherent climatic and geographical challenges. For instance, the Desert region, characterized by its large average median lot size, reports the highest water usage. In contrast, the Bay Area and North Coast regions have smaller average median lot sizes, which correlate with lower water consumption. The economic characteristics of these regions, represented by the average median home values, also show variation across different regions. The Bay Area region, despite its lower water usage and small median lot size, boasts the highest average median home value. The Desert region, conversely, despite its higher water consumption and larger lot sizes, reports the lowest median home value. Another important observation from the summary statistics in table 2 is the relative age of the housing stock across regions. The Central and Desert regions, with higher median years for house built of (1980 and 1984, respectively), indicate a recent surge

[3] These 189 water agencies cover approximately 80% of the California residential water consumption (providing water to more than 23 million people in the state).
[4] See appendix table A1 for summary statistics of key variables for all years (2003-2021).

in housing developments. This contrasts with other regions where the housing stock is comparatively older.

Table 4 presents a comparative analysis of the characteristics of small and large lot sizes within our sample. It reveals significant differences in water consumption between the two categories. Specifically, water agencies that have a greater share of large lot size households have substantially higher mean and median water consumption compared to those with predominantly small lot size households. Interestingly, the data contradicts conventional expectations regarding house values. The average median house value in the large lot size category is about 5% lower than that in the small lot size category. This is likely due to regional factors, such as the lower home values prevalent in inland and central regions compared to coastal regions. The table also highlights a noticeable disparity in the percentage of pools between the two categories. The large lot size category boasts a significantly higher percentage of pools at 17% compared to 7% in the small lot size category. This could be a key factor contributing to the observed higher average water consumption in this category.

These variations in water use and household characteristics across regions and lot size categories underscore the importance of including these variables in our estimation strategy to ensure a comprehensive analysis of water use patterns.

6. Empirical Methods

This paper follows a water demand estimation similar to previous studies (Hewitt and Hanemann, 1995; Buck et. al., 2016, Solimon, 2021). Specifically, it assumes that the average monthly gallons per capita per day (gpcd) in water agency *i* during month *m* in year *t* is given by:

$$(1)\ \text{Log } Y_{imt} = \beta_0 + \beta_1 \text{Log (P)}_{im\text{-}1t} + \beta_2 \text{ LotSize}_{it} + \beta_3 \text{ Temp}_{imt} + \beta_4 \text{ Precip}_{imt} + \beta_5 \text{PopulationDensity}_{imt} + \beta_6 \text{ HouseValue}_{it} + \sum[\alpha_r(\text{Region}_r)_i \times \text{LotSize}_{it}] + \sum[\omega_j Z_{jit} \times \text{LotSize}_{it}] + \gamma X + \sigma_i + \mu_t + \varepsilon_{imt}$$

The model is estimated using fixed effects, where the dependent variable is the logarithm of average monthly gallons per capita per day (GPCD) water consumption in water agency i in month *m* in year *t*. As the main focus of this paper, we hypothesize that households with different lot sizes will respond differently to changes in price, population density, temperature, house vintage and presence of a pool, and in different regions that have different climate and hydrologic conditions, so we also include interaction terms for lot size categorical variables with these variables in our estimation. X represents household characteristics such as bathrooms, rooms, presence of a pool, homeowner occupied households, housing vintage.

To characterize indoor water use, we estimate the main effects of median living area size, the median number of bathrooms, and the percent pool ownership in the model. Following previous studies (e.g., El-Khattabi et al., 2022), we proxy household wealth by the assessed home value.

Water literature shows that building age influences urban water demand (Brelsford, C. and Abbott, J., 2017). Therefore, we include a categorical variable for house vintage that is equal to 1 for old vintage if the share of households in quartiles 1 and 2 of median year-built is greater than the share of households in quartiles 3 and 4, zero otherwise. This is important to include because the age of a house captures the quality and type of plumbing system in place. For alternative specification, we also include a categorical variable taking 1970 as a reference year.

More densely populated water agencies are expected to have increased urbanization, and different infrastructure that can influence water consumption patterns differently than in less densely populated water agencies. For this reason, we created a population density measure that is calculated using the population served by each water agency divided by the area covered by that water agency. By controlling for population density, we can help account for these potentially confounding factors that may affect water consumption beyond per capita measures.

Following (Buck et al. 2021), we assume the equilibrium price of water to be the price on the median tier of the water agency's tier price schedule. We use the 1-month lagged price value to account for the fact that households are likely to react to a price change after receiving their utility bill (Ito, 2014). We use monthly means of temperature and precipitation within each agency to control for the weather.

We construct several variables of lot size, all measured at the agency level. In our main strategy, we use a categorical variable for lot size calculated as 1 for large lots when the share of houses quartiles 3 and 4 in a water agency is greater than the share of houses in quartiles 1 and 2 of median lot size calculated using tax assessor data for California. In alternative specifications, we use median lot size in square feet within an agency as a measure for lot size. We also construct categorical variables for lot size based on whether the median lot size in an agency is greater than 15,000 square feet for large lots (or less than 7,000 square feet for small lots). We include quartiles of lot sizes and the shares of houses in each agency within each quartile as separate measures for lot size. Lastly, we are able to calculate estimates of these variables within an agency over time.

7. Results

Tables 5A1-A4 show the main estimation results of the paper. Table 5A1 (Panel A) of the table shows the results of the base model with no interactions and provides an estimate of the direct impact of lot size and the other variables in the model on household water consumption.

Table 5A2 (Panel B) includes interaction terms between lot size and price, population density, temperature, house vintage, and pool variables. This allows us to assess how the relationship between lot size and water consumption is affected by these interactions. The main effects are also included to account for the individual impact of each variable on water use.

In Table 5A3 (Panel C), we incorporate regional heterogeneity by interacting lot size with different regions (Bay Area and North Coast, South Coast, Deserts, and Central Coast regions. Central Region is used as the reference group). This helps provide some insight into how the relationship between lot size and water consumption may differ across regions.

Lastly, in Table 5A4 (Panel D), we provide estimates of price elasticity of water demand across regions.

Price elasticity of water demand is consistently significant and within a range similar to previous studies (Mansur and Olmstead, 2012; Renwick and Green, 2000), indicating that as the price increases, water consumption tends to decrease. Secondly, lot size has a positive and significant impact on water consumption across all model specifications, which suggests that water use is higher in water agencies where larger lots are more common. The coefficient of lot size and price interaction shows a positive and highly significant result. When water prices go up, people with larger lots use water more carefully. This shows that higher water prices can help control water use, especially for large lots. For the Deserts region, the price elasticity estimate is positive, suggesting that water agencies with large lots in the region have less flexibility to reduce water usage, perhaps due to the need for irrigation in the dry and hot climate. Overall, the price elasticity estimates suggest that large lots are generally more responsive to price changes than small lots, which could be due to larger lots having more discretionary water use (e.g., outdoor use to maintain lawns or landscaping) that they can cut back on when the price increases. However, the exact pattern varies by region, which suggests that local factors like climate and the types of water usage are important determinants of water demand.

Population density has a negative and highly significant relationship with water consumption. This could be due to a variety of factors such as denser areas having smaller lots and hence smaller outdoor use, or the presence of more efficient water usage practices in densely populated areas. However, estimates of the interaction terms between lot size and population density suggest that as population density increases, the effect of having larger lots on water usage increases as well. That is, the positive impact of larger lots on water usage per capita is more pronounced in densely populated areas. This could be because larger lots in densely populated areas are more likely to have more extensive outdoor use that require increased water usage compared to smaller lots in the same area.

According to our estimation results, lot size when interacted with the age of the housing stock, shows a negative relationship with water consumption, implying that as homes get older, the effect of lot size on water consumption decreases. One possible explanation for this could be that older homes on larger lots have more mature, water-efficient landscapes or have made improvements to their water infrastructure over time. Therefore, in water agencies overseeing areas with a higher proportion of older homes, the role of lot size in determining water use might be less pronounced than in areas with newer homes.

Our results also reveal significant regional heterogeneity in the relationship between lot size and water consumption. Specifically, the interactive coefficients of lot size and the South Coast, Desert, and Central Coast regions are all significantly negative. This could suggest that in these regions, the positive association between lot size and residential water consumption is less pronounced compared to the Central region of California. These variations could be due to multiple factors such as differences in climate, water resource availability, regional differences in efficiency of promoting water conservation practices, or even the predominance of certain landscaping practices. Understanding these regional differences is, therefore, important for shaping effective and targeted water conservation policies.

Overall, the results suggest that larger lots are associated with higher average per capital per day water use, and this effect is stronger in water agencies with a higher population density. Additionally, there is regional heterogeneity in the relationship between lot size and water usage, with the effect of large lots being significantly different across regions.

8. Lot size composition and the 2015 drought mandate

To further investigate the underlying structural factors contributing to water usage patterns across water agencies, we focus on the 2012-2016 drought period in California, and more specifically the 2015 governor drought mandate that placed mandatory restrictions on water suppliers and aimed to achieve a 25% statewide reduction by February 2016. Using this mandate as a policy intervention and the two lot size categories as treatment (large lots) and control (small lots), we attempt to investigate whether lot size played a significant part in reducing water use across agencies. Using a Difference-in-Differences framework, we provide preliminary evidence for a relationship between lot size and water conservation efforts by exploiting the variation in water use across lot size categories introduced by the drought mandate, while controlling for characteristics unique to each water agency. Specifically, we compare changes in water usage between agencies with a higher share of large lots, which we hypothesized would have more discretionary water usage and hence greater potential for reduction, and those with a higher share of small lots which would have little room to have reductions. By doing so, we are able to quantify the differential impact of the drought mandate on these two groups at the water agency level and, consequently, gain insight into the effectiveness of the mandate in inducing water conservation in areas with different housing characteristics.

To effectively employ a difference-in-differences approach, the critical parallel trends assumption must be satisfied. This assumption states that, in the absence of treatment (in our case, the drought mandate), the treated group (large lot size) and the control group (small lot size) would have followed the same trend over time. This assumption is vital because it underpins the main idea of difference-in-differences - that the only difference between the control and treatment groups is the treatment itself. In the context of our study, Figure 2 illustrates that the average water use across the two lot size categories indeed follows a similar trend prior to the 2015 drought mandate. This visual evidence provides support for the parallel trend assumption. Consequently, any divergence in the trends of the two groups immediately after the implementation of the drought mandate can be attributed to the impact of the mandate[5].

Additionally, water agencies were assigned a different conservation target based on their baseline water usage of July-September 2014. A total of nine tiers were created and (see Table 6)

[5] One key assumption we make is that the lot-size classification remains the same within each year since our lot size data is yearly and not monthly.

each water agency was assigned a conservation tier group based on its baseline water usage. In our estimation, we control for this tiered conservation system.

The difference-in-differences equation estimated is as follows:

$$\text{(2) Log } Y_{imt} = \beta_0 + \beta_1 \text{ DroughtMandate}_{mt} + \beta_2 \text{ LotSize}_{it} + \beta_3(\text{DroughtMandate}_{mt} \times \text{LotSize}_{it}) + \gamma X + \sigma_i + \mu_t + \varepsilon_{imt}$$

where the dependent variable is log of gpcd (gallons per capita per day) in water agency *i* in month *m* and year *t*. Drought Mandate is a categorical variable equal to 1 if the drought mandate was in effect (June 2015-March 2016), 0 otherwise. We control for variables that vary across lot size groups such as price, median home value, weather, pool, bathrooms, vintage, and population density. All the variables are defined as before.

Estimation results for equation (2) are in Table 7. The results suggest that the drought mandate led to a decrease of approximately 15% in the residential water use across all water agencies in California. However, according to our estimates, the effect of the drought mandate was smaller in agencies with a high share of large lots compared to agencies with high share of small lots, suggesting that the mandate was more effective in water agencies with more small lots. This could be due to several reasons. For example, water agencies with more single-family households located on small lots might be able to enforce restrictions more easily and therefore have better compliance with the mandate. On the other hand, there may be higher rates of non-compliance with the mandate in water agencies with higher share of large lots, either because households in these areas can afford to pay any fines for non-compliance, or because enforcement of the mandate is less stringent in these water agencies. It is also possible that water agencies with more small lots have more efficient water infrastructure or have been more proactive in implementing water-saving technologies and practices thereby leading them to react more strongly to the drought mandate.

9. Concluding Remarks

In this paper, we investigate the heterogeneous nature of water use by carrying out an empirical estimation of water demand for single-family residential households across water agencies in California from 2003 to 2019, distinguishing between water agencies with different structural and demographic characteristics, particularly lot size, to estimate how these factors affect water use. Our estimates use temporal variation in lot size across space to shed light on the potential effects of housing development and composition on residential water use. The results of this paper provide important policy insights by identifying key factors that vary across water agencies and are important determinants of water use.

One of the main limitations of this paper lies in the measurement of lot size. Potential measurement errors may arise from the methods used to assess lot sizes, and these inaccuracies could be further magnified when data is aggregated to the water agency level. Moreover, aggregating lot size data at the water agency level may obscure the true extent of variation in lot sizes. Additionally, the time period of this study might not capture the full range of lot size fluctuations that could be observed over a longer timescale. To address these limitations, future research can employ more precise methods for measuring lot size and explore the impact of lot size variation at different temporal scales and finer spatial scales, such as at the household level, rather than relying on aggregated data at the water agency level.

Future research could also extend this analysis by improving on the methodology of this paper and incorporating the impacts of climate change predictions on water demand patterns in households of different lot sizes. These studies can also incorporate the role of innovative water saving technologies, such as smart water systems, in optimizing water use across different lot sizes.

Tables and Figures

Table 1: Percentage change in single-family residential lot size (median sqf)

Region	All California	Bay Area & North Coast	Deserts Region	Central Region	Central Coast	South Coast
Lot Size (sqf)	9,858	6,955	20,096	9,637	10,203	8,900
Percent change in Median Lot size (2006-2021)[a]	+59%	+9%	+31%	+56%	+32%	+4%

[a] calculated using tax assessor data for California.

Table 2: Variable Definitions

Variable	Definition
GPCD	Average water consumption by single-family households in a water agency (gallons per capita per day)
Average Price	Average price on the median tier of the water agency’s price schedule ($)
Lot Size	Median lot size within a water agency (square ft)
Population Density	Total population served by water agency divided by total area covered by that water agency
Temperature	Average monthly temperature in a water agency (Celsius)
Precipitation	Average monthly precipitation in a water agency (millimeters)
Vintage	Median year built for single-family households in a water agency
Pool	Percent of single-family households with a pool in a water agency
Home Value	Median single-family house value in a water agency ($)
Region	Categorical variable for region
Climate Zone	Categorical variable for building climate zone
Coastal	Categorical variable for coastal region
Summer	Categorical variable for summer months
Winter	Categorical variable for winter months
Ownership	Percent ownership of single-family households in a water agency
Bathroom	Median number of bathrooms in a water agency
Room	Median number of rooms in a water agency

Table 3: Summary stats by region

Region	GPCD	Price	Precip	Temp.	Value	Owned	Pool	Lot Size	Baths	Built
Bay Area and North Coast	79.45	3.89	46.70	14.87	518k	0.80	0.08	6,955	1.94	1965
Central	128.17	1.85	44.60	15.82	204k	0.76	0.12	9,637	1.94	1981
Central Coast	80.01	4.65	42.47	15.14	454k	0.69	0.03	10,203	2.05	1980
Deserts	119.68	2.37	23.68	16.55	186k	0.59	0.10	20,096	1.75	1984
South Coast	105.10	2.69	28.21	17.94	434k	0.77	0.17	8,900	2.14	1964

Table 4: Household characteristics by lot size category

	Lot size category			
Variables	**Small Lot**		**Large Lot**	
	Mean	**Median**	**Mean**	**Median**
Price	3.27	2.75	2.70	2.32
GPCD	85.44	76.95	127.20	110.66
House Value	377k	333k	405k	315k
Owned	77%	79%	73%	77%
Pool	8%	7%	18%	17%
Lot Size (sqf)	5,843	6,098	12,329	7,890
Year Built	1967	1965	1974	1976
Bathrooms	1.91	2.00	2.18	2.00
Precipitation	35.36	9.42	36.18	10.73
Temperature	16.62	16.38	16.98	16.69

Table 5A1: Estimation Results

	Dependent Variable: Log GPCD			
	Model (1)	**Model (2)**	**Model (3)**	**Model (4)**
Panel A: Main Effects				
Log Price	-0.2550***	-0.2849***	-0.2723***	-0.6005***
	(0.0070)	(0.0079)	(0.0082)	(0.0360)
Lot Size	0.0871***	0.3429***	0.3200***	0.3528***
	(0.0098)	(0.0599)	(0.0681)	(0.0751)
Population Density	-0.0907***	-0.1115***	-0.1018***	-0.1182***
	(0.0037)	(0.0042)	(0.0047)	(0.0048)
Summer	0.0512***	0.0489***	0.0478***	0.0483***
	(0.0064)	(0.0063)	(0.0063)	(0.0105)
Precipitation	-0.0005***	-0.0004***	-0.0004***	-0.0004***
	(0.00005)	(0.00005)	(0.00005)	(0.00005)
Tmax	0.0310***	0.0294***	0.0292***	0.0291***
	(0.0006)	(0.0008)	(0.0008)	(0.0007)
Log Home Value	-0.0671***	-0.0391***	-0.0328***	-0.0082
	(0.0102)	(0.0104)	(0.0112)	(0.0114)
Vintage	-0.0551***	0.1311***	0.0769***	-0.0141
	(0.0213)	(0.0253)	(0.0279)	(0.0375)
Baths	0.0383***	0.0505***	0.0573***	0.0557***
	(0.0100)	(0.0100)	(0.0106)	(0.0106)
Owner Occupied	0.0633**	0.0751***	0.0798***	0.0846***
	(0.0285)	(0.0282)	(0.0304)	(0.0315)
Pool	1.3635***	0.5971***	0.4757***	0.1330
	(0.0451)	(0.0801)	(0.0846)	(0.1818)

Notes: *p < 0.10; **p < 0.05; ***p<0.01

In Model (1), lot size is a continuous variable measured by median lot size of an agency in square feet.

In Models 2, 3 and 4, lot size is a categorical variable equal to 1 if share of single-family residential households within an agency in quartiles 3 & 4 of lot size is greater than the share of single-family residential households in quartiles 1 & 2; 0 otherwise.

Table 5A2: Estimation Results

Panel B: Interaction Effects	**Model (2)**	**Model (3)**	**Model (4)**
Lot Size, Price	0.0489*** (0.0109)	0.0437*** (0.0126)	0.1391*** (0.0497)
Lot Size, Pop. Density	0.0534*** (0.0071)	0.0379*** (0.0079)	0.0606*** (0.0082)
Lot Size, Tmax	0.0050*** (0.0008)	0.0057*** (0.0009)	0.0064*** (0.0008)
Lot Size, Vintage	-0.3886*** (0.0317)	-0.3464***(0.0353)	-0.2933*** (0.0566)
Lot Size, Pool	1.0710*** (0.0847)	1.1353*** (0.0923)	0.6861*** (0.1976)

Notes: *p < 0.10; **p < 0.05; ***p<0.01
Lot size is a categorical variable equal to 1 if share of single-family residential households within an agency in quartiles 3 & 4 of lot size is greater than the share of single-family residential households in quartiles 1 & 2; 0 otherwise.

Table 5A3: Estimation Results

Panel C: Regional Heterogeneity (Reference group: Central Region)	**Model (3)**	**Model (4)**
Small lots, Bay Area	-0.0743*** (0.0232)	-0.2717*** (0.0363)
Small lots, South Coast	-0.1564*** (0.0336)	-0.2524*** (0.0423)
Small lots, Deserts	0.0238 (0.0417)	0.8803** (0.4019)
Small lots, Central Coast	-0.1460*** (0.0325)	-0.4122*** (0.0572)
Lot Size, Bay Area	-0.0427 (0.0365)	-0.0818 (0.0862)
Lot Size, South Coast	-0.1391*** (0.0311)	-0.0203 (0.0407)
Lot Size, Deserts	-0.3228*** (0.0540)	-0.8723** (0.4107)
Lot Size, Central Coast	-0.0930** (0.0399)	0.3529*** (0.0397)

Notes: *p < 0.10; **p < 0.05; ***p<0.01

Lot size is a categorical variable equal to 1 if share of single-family residential households within an agency in quartiles 3 & 4 of lot size is greater than the share of single-family residential households in quartiles 1 & 2; 0 otherwise.

Table 5A4: Estimation Results

Panel D: Elasticities across Regions	**Model (4)**	**Price Elasticities**
Small lots, Bay Area	0.3310*** (0.0353)	-0.2695
Small lots, South Coast	0.1732*** (0.0329)	-0.4273
Small lots, Deserts	-1.0455** (0.4888)	-1.646
Small lots, Central Coast	0.3529*** (0.0397)	-0.2476
Small lots, Central Region	-	-0.600
Large lots, Bay Area	-0.0849 (0.0716)	-0.5463
Large lots, South Coast	-0.1187** (0.0508)	-0.5801
Large lots, Deserts	0.9114* (0.4932)	0.450
Large lots, Central Coast	-0.1568** (0.0616)	-0.6182
Large lots, Central Region	-	-0.4609

Notes: *p < 0.10; **p < 0.05; ***p<0.01

Lot size is a categorical variable equal to 1 if share of single-family residential households within an agency in quartiles 3 & 4 of lot size is greater than the share of single-family residential households in quartiles 1 & 2; 0 otherwise.

Table 6: Conservation tiers for 2015 drought mandate

	R-GPCD Range		
Tier	From	To	Conservation Standard
1	Reserve	Reserve	4%
2	0	64.99	8%
3	65	79.99	12%
4	80	94.99	16%
5	95	109.99	20%
6	110	129.99	24%
7	130	169.99	28%
8	170	214.99	32%
9	215	612	36%

Source: California State Water Resources Control Board.

Table 7: Difference in Differences Model Summary

	Dependent variable:
	Log GPCD
Drought Mandate	-0.1490*** (0.0106)
Lot Size	-0.0078 (0.0128)
Drought Mandate, Lot Size	-0.0286* (0.0163)
Price	-0.1681*** (0.0097)
Population Density	-0.9388*** (0.0173)
Precipitation	-0.0003*** (0.00005)
Temperature	0.0372*** (0.0005)
Home Value	-0.1835*** (0.0149)
Vintage	0.4268*** (0.0588)
Baths	0.0068 (0.0127)
Owner Occupied	-0.0004 (0.0295)
Pools	-0.5732*** (0.0926)
Observations	8,032
R^2	0.6445
Adjusted R^2	0.6410
Note:	*p <0.10; **p <0.05; ***p<0.01

Figure 1: Percent change in water use across lot size categories over time (base year 2003).

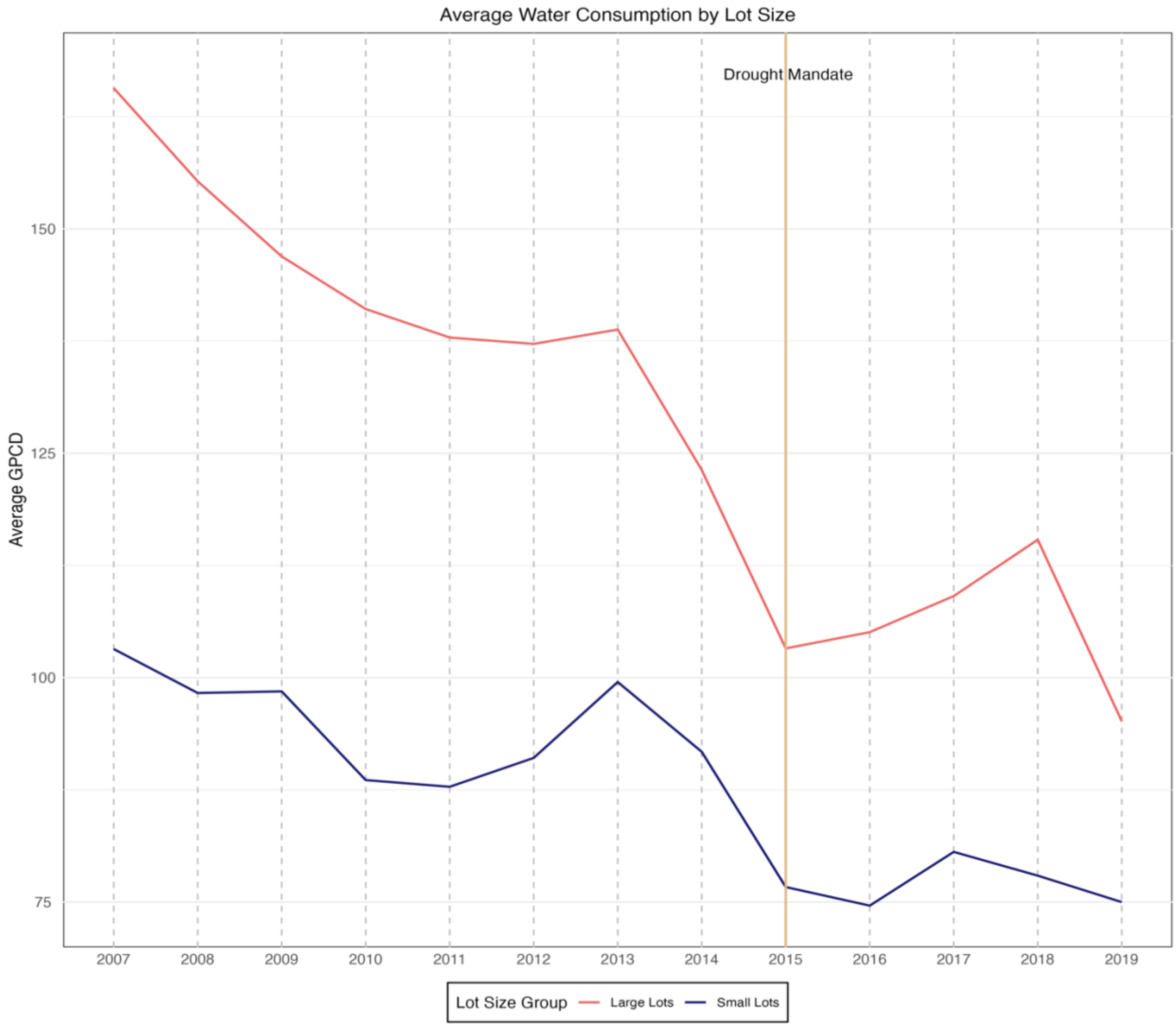

Figure 2: Average water use (GPCD) by each lot size group showing a parallel trend across both groups prior to the intervention (drought mandate). The parallel trend assumption is key to the Difference-in-Differences framework.

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Appendix:

Table A1: Household characteristics and water use across time

Year	GPCD	Price	Precip	Temp	Value	Owned	Pool	Lot Size	Baths	Built
2003	115.85	1.70	32.54	16.98	318k	0.91	0.11	5,894	2.08	1959
2004	117.86	1.86	39.53	16.63	338k	0.89	0.09	5,895	2.04	1960
2005	103.62	2.01	54.98	16.32	360k	0.92	0.10	5,823	2.01	1962
2006	109.50	2.08	35.39	16.56	419k	0.91	0.10	5,721	2.07	1962
2007	121.76	2.13	18.20	16.35	490k	0.88	0.10	5,992	2.06	1962
2008	118.33	2.20	32.41	16.74	510k	0.77	0.10	6,230	2.06	1963
2009	119.65	2.29	26.91	16.70	412k	0.83	0.11	8,635	2.11	1967
2010	109.72	2.53	57.45	15.84	373k	0.75	0.12	7,859	2.12	1968
2011	109.56	2.74	32.02	15.52	369k	0.71	0.12	8,455	2.14	1968
2012	117.10	2.75	31.09	16.70	340k	0.70	0.13	8,734	2.10	1970
2013	119.32	2.82	11.23	16.61	308k	0.67	0.12	8,551	2.10	1972
2014	123.20	3.03	29.20	17.83	325k	0.71	0.12	8,640	1.98	1970
2015	95.72	3.33	20.17	17.66	340k	0.72	0.13	9,228	2.01	1971
2016	95.49	3.45	37.20	17.27	359k	0.74	0.13	9,233	2.00	1971
2017	101.09	3.69	41.78	17.43	377k	0.74	0.13	8,591	2.01	1971
2018	102.05	3.98	28.58	17.32	401k	0.74	0.13	8,615	1.99	1971
2019	96.13	4.11	62.15	15.73	432k	0.75	0.13	8,629	2.03	1971
2020	106.48	-	-	-	473k	0.77	0.13	8,753	2.05	1971
2021	103.69	-	-	-	410k	0.80	0.13	9,102	2.04	1972

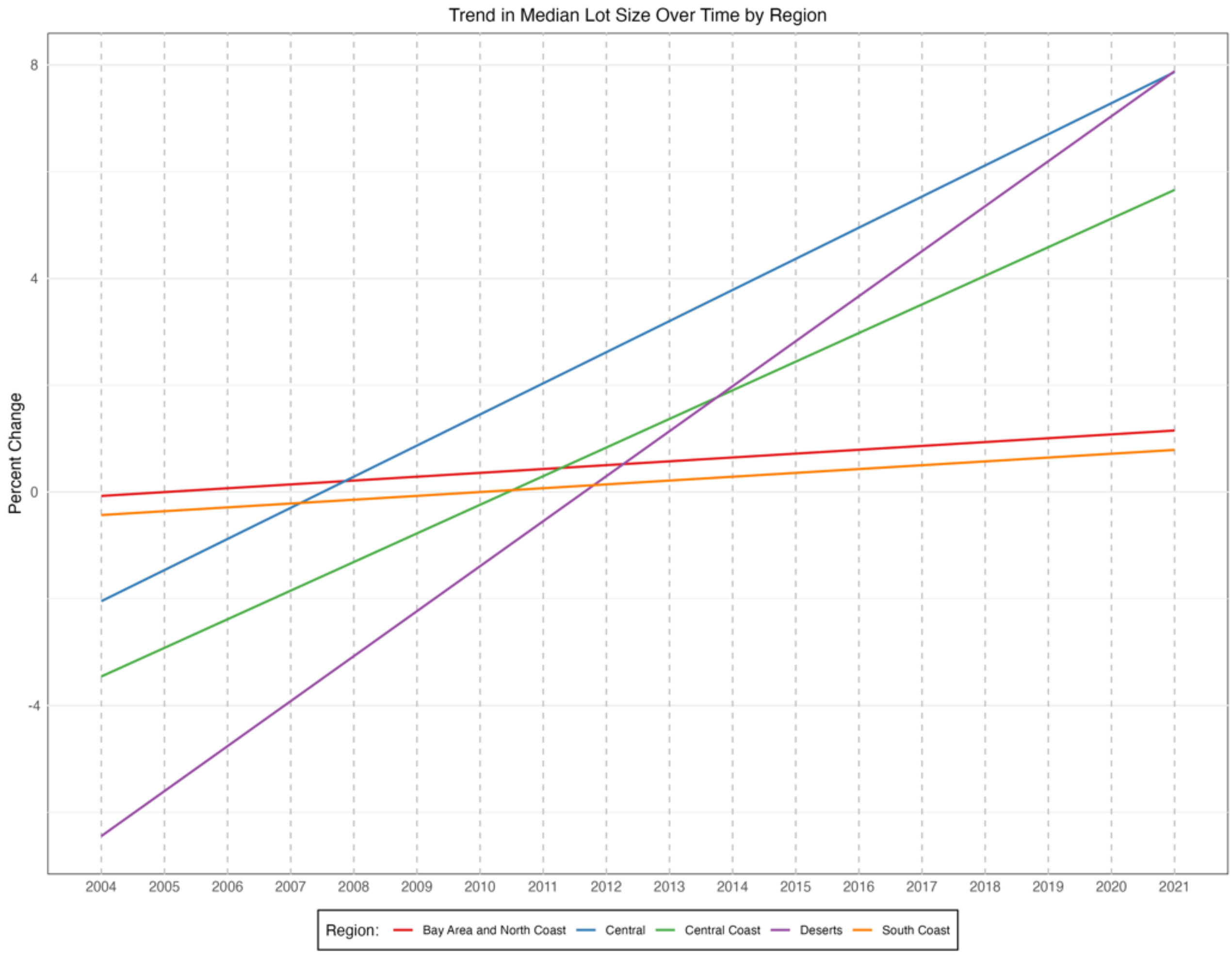

Figure A1: Trend in percent change median lot size over time by region in California.

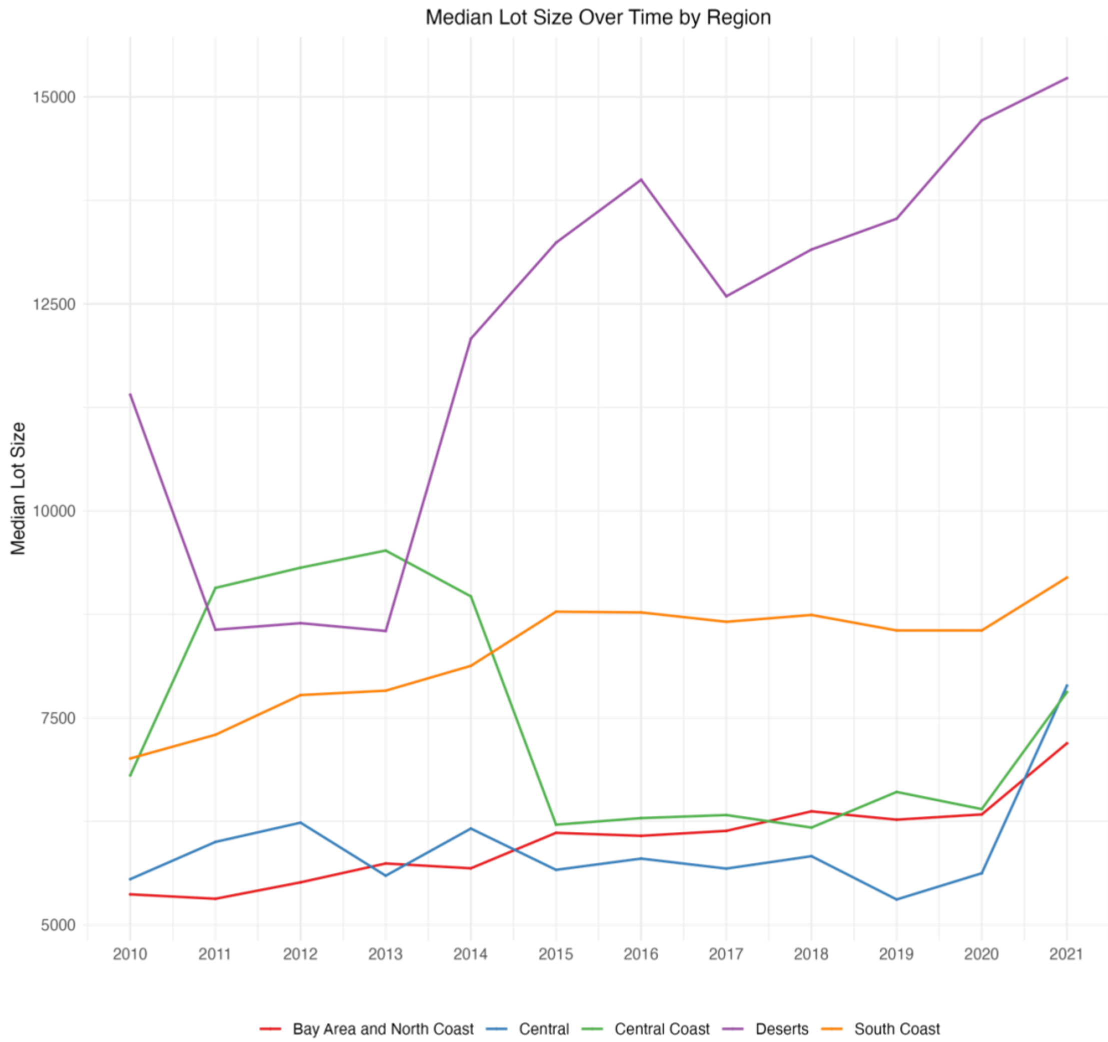

Figure A2: Median lot size (sqf) across regions in California (2010-2021)