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Key Points:
- Water conservation is analyzed from the perspective of water retailers
- The study compares price and nonprice conservation measures with panel data
- Mandates are effective, rates or rebates are not, large agencies perform well

Supporting Information:
- Readme
- List of Urban Water Management Plans

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Water demand management in times of drought: What matters for water conservation

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Abstract Southern California is subject to long droughts and short wet spells. Its water agencies have put in place voluntary, mandatory, and market-based conservation strategies since the 1980s. By analyzing water agencies' data between 2006 and 2010, this research studies whether rebates for water efficient fixtures, water rates, or water ordinances have been effective, and tests whether structural characteristics of water agencies have affected the policy outcome. It finds that mandates to curb outdoor water uses are correlated with reductions in residential per capita water usage, while water rates and subsidies for water saving devices are not. It also confirms that size is a significant policy implementation factor. In a policy perspective, the transition from a water supply to a water demand management-oriented strategy appears guided by mandates and by contextual factors such as the economic cycle and the weather that occur outside the water governance system. Three factors could improve the conservation effort: using prices as a conservation tool, not only as a cost recovering instrument; investing in water efficient tools only when they provide significant water savings; supporting smaller agencies in order to give them opportunities to implement conservation strategies more effectively or to help them consolidate.

1. Introduction

Freshwater scarcity is a problem in many parts of the world. Many poor countries experience scarcity due to climate and lack of infrastructure, while industrialized nations experience conflicts among different uses, water-quality degradation, and droughts.

Water management organizations in many industrialized countries are facing increasing supply shortages and assert that conservation is one of their primary strategies to address water scarcity and to reduce the pressure of interest groups for providing new reservoirs and expensive new infrastructure. Many state water plans in the United States proclaim that only by reducing urban water usage can future supplies be sufficient to respond to urban, agricultural, and environmental demands. In times of drought, politicians appeal to citizens' civic spirit, exhort them to reduce water usage and urge water providers to design and adopt water conservation strategies.

In California, water agencies have implemented a range of voluntary and mandatory conservation measures and per capita urban usage has been on the decline for several years, but it is unclear whether this is due to successful conservation policies or to other factors, such as deindustrialization, and trends in less water intensive technological innovation.

Studies on water conservation adopt a range of different perspectives. Technical studies assess the effectiveness of individual conservation devices [*Campbell et al.*, 2004; *Hanemann and Nauges*, 2005; *Kenney et al.*, 2008; *Lee*, 2011; *Mayer et al.*, 2009; *Mayer and DeOreo*, 1999; *Renwick and Green*, 2000; *Renwick and Archibald*, 1998; *Tsai et al.*, 2011]. Numerous studies in the United States and elsewhere focus on price and the elasticity of water demand [*Arbués et al.*, 2003; *Dalhuisen et al.*, 2003; *Worthington and Hoffman*, 2008]. There are many assessments of the efficiency of market strategies and mandates [*Brennan et al.*, 2007; *Grafton and Ward*, 2008; *Hensher et al.*, 2006; *Mansur and Olmstead*, 2012; *Timmins*, 2003]; however, most studies analyze individual households' behaviors, rather than the policies underlying them. Field-based research is usually limited to a few water agencies and conducted over relatively short-time periods. Only a few analyses have examined water conservation strategies from the perspective of the responsible water agencies [*Hughes*, 2012].

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This research takes the next innovative step. It treats water conservation as the result of policy actions. It focuses on the effects of a range of conservation strategies implemented by water agencies in Southern California between 2005 and 2010 and analyzes whether they have been effective and whether some characteristics of said agencies have influenced policy implementation. It does so through the analysis of an original data set, that includes water rates, demographic information, and data on rebates for water-efficient equipment at the water retailer level that had never been compiled before.

The geographic area of analysis has unique characteristics. California has a long history of laws, policies, and practices in support of water conservation. Southern California water agencies depend on water supply from the Colorado River and Northern California and are subject to long droughts and short wet seasons. Since the late 1980s, they have been testing numerous concurrent conservation strategies: education, mandates, pricing, and subsidies for water-efficient equipment and they have been very vocal about their commitment to conservation, more so in times of drought, and less in times of wet weather. This research tests whether they have been effective and how the characteristics of the adopting agencies have affected their policies' outcomes.

The paper is organized in three sections. The first is a discussion of the multitheoretical approaches to water conservation. The second is a summary of the history of Southern California water conservation effort. The third is devoted to the method and data used in the research, the findings, and a discussion of their validity and relevance in a policy perspective.

In brief, the major substantive finding is that mandates are by far the most effective approach to reducing water consumption when compared to pricing and/or providing subsidies for water saving devices. Also, the size of the water agency is a significant factor in the implementation of water conservation strategies.

2. Water Conservation as Natural Resources and Water Demand Management

2.1. Natural Resources Management

Water conservation is the result both of the conscious effort of water agencies' policies and of individuals' behaviors [*Inman and Jeffrey*, 2006]. This study takes these aspects into account and refers to the research on water resources management and to the research on water demand.

Nature and characteristics of natural resources are primary elements of analysis of the literature on natural resources management [*Ostrom*, 2009; *Wiek and Larson*, 2012; *Young*, 2002, 2010], fundamental components of environmental policy analysis [*Sabatier*, 1988] and essential features of the analysis of complex socioecological systems and their governance [*Anderies and Janssen*, 2013]. Studies of small common pool resources (CPR) systems in developing countries provide evidence of how the relationship between environmental resources and human organizations function, however, it is not clear how their claims can be applied to more complex situations in developed countries [*Anderies and Janssen*, 2013].

Water management analysts make an effort to shade light on the relationship between resources endowment and water agencies' performances. Their attention is on water governance, on the characteristics of water regimes, and on their adaptability to environmental changes [*Huitema et al*., 2009; *Ostrom*, 1990; *Pahl-Wostl et al*., 2013; *Saleth and Dinar*, 2004, 2005]. Their emphasis is on the characteristics of natural resources, on centralization and polycentricism, on the interactions among formal and informal norms, on policy, and on the characteristics of management organizations.

As an effort to explore this relationship, this study's first hypothesis is that the local endowment of natural resources affect the agencies' ability to improve their conservation performance and that water agencies with an ample supply of local, inexpensive, water are less likely to implement water conservation strategies effectively (H1).

Organizational fragmentation is also a topic of concern and interest. The scale of natural resources management regimes is a relevant issue in environmental policy [*Padt et al*., 2014; *Termeer, et al*., 2010; *Young*, 2002] and the discussion on the most effective size of natural resources managing organizations is wide open. Studies on water governance claim that fragmented water agencies are less likely adopt adaptive management practices [*Pahl-Wostl and Knieper* 2014] and that only decentralized but heavily connected CPR management systems provide public services effectively [*Dietz et al*., 2003; *McGinnis*, 2000; *Ostrom*, 2010; *Ostrom* *et al*., 1961] and are more resilient and adaptive [*Pahl-Wostl et al*., 2013]. Empirical research, although sparse, finds that centralized, large, and complex organizations manage urban water more effectively than small and fragmented systems [*Heikkila*, 2004; *Saleth and Dinar*, 2004]. Water managers agree that centralization is key to a better performance [*Saleth and Dinar*, 2004] and that larger water districts are more likely to implement complex policies like conjunctive management than smaller agencies [*Heikkila*, 2004]. Even when managing public goods, centralized water governance systems are more flexible and manage water supply according to the fluctuations of water availability more effectively than fragmented and loosely connected systems [*Schlüter and Pahl-Wostl*, 2007].

Drawing from these analyses, the second hypothesis of this research is that size of the organization implementing water conservation policies matters; that larger organizations manage water conservation initiatives more effectively (H2).

2.2. Water Demand Management

2.2.1. Water Demand Models and Water Pricing

While the analysis of water management systems focuses primarily on norms, organizations, policy, and the nature of the resource, water demand analysis studies the relationship between individuals and water consumption in residential settings. Anthological studies summarize the characteristics of the water-demand function, identify major themes of inquiry, analyze challenges and gaps in the research, and assess its implication for water conservation [*Arbués et al*., 2003; *Worthington and Hoffman*, 2008].

Weather, rates, income, household composition, housing characteristics, frequency of billing, and type of outdoor irrigation are major drivers of residential water demand [*Arbués, et al*., 2003; *Duke et al*., 2002; *Grafton et al*., 2010; *Hewitt and Hanemann*, 1995, *Olmstead et al*., 2007; *Olmstead and Stavins*, 2008; *Ramachandran and Johnston*, 2011; *Shandas and Parandvash*, 2010; *Shearer*, 2009; *Wentz and Gober*, 2007; *Worthington and Hoffman*, 2008]. Only recently, the analysis has taken into account consumers' behaviors and attitudes and new studies include consumers' believes as potential drivers of water consumption [*Adams et al*., 2013; *Beal et al*., 2010; *Cook et al*., 2012; *March et al*., 2010].

Local weather is an important driver of water usage. Temperatures and precipitations are considered important variables in every demand management model [*Arbués et al*., 2003]. Other relevant factors are elasticity of water demand to price, urban density, and consumers' attitudes. Most studies estimate that, at current rates, urban water demand is inelastic and negative and ranges between -0.02 and -0.77 [*Worthington and Hoffman*, 2008]. This measure, however, is highly variable and studies using the same method report widely different results [*Worthington and Hoffman*, 2008]. Many factors influence water price elasticity. The most important is rate structure. Water rates are complex. In the simplest case, they are composed of a fixed charge and a volumetric charge. In many cases, volumetric charges are segmented in blocks so the rate consists of a sequence of different marginal prices for different consumption blocks. The block rate can be ascending: the higher is consumption the higher the rate; or descending. More complex rates assign each customer a water budget with a very low rate and apply higher rates to overbudget customers. Summary studies find that price elasticity is higher for ascending block pricing [*Dalhuisen et al*., 2003; *Olmstead et al*., 2007], but also that price elasticity is smaller in the winter [*Hanemann and Nauges*, 2005], elasticities are lower for renters rather than for homeowners, and low income customers' demand has lower elasticity than high income's [*Duke et al*., 2002; *Grafton et al*., 2010; *Renwick and Archibald*, 1998; *Worthington and Hoffman*, 2008]. Outdoor uses are more elastic than indoor [*Mansur and Olmstead*, 2012], and for smaller properties price elasticity is lower than for larger properties [*Adams et al*., 2013].

Housing characteristics have emerged as a very relevant element of water demand modeling [*Breyer et al*., 2012; *Harlan et al*., 2009; *House-Peters et al*., 2010; *Nauges and Thomas*, 2003; *Ramachandran and Johnston*, 2011; *Shandas and Pavarandash*, 2010; *Shearer*, 2009; *Wentz and Gober*, 2007]. The positive correlation between size of outdoor space and household water demand has been tested in numerous instances [*Guhathakurta and Gober*, 2010; *Hanak and Davis*, 2006; *House-Peters and Chang*, 2011; *Kenney et al*., 2008; *Syme et al*., 2004], as well as the negative correlation between density and water demand patterns [*Fox et al*., 2009; *Polebitski et al*., 2011].

A newer group of studies, finally, takes into account consumers' behaviors and attitudes and analyzes consumers' believes as one of the important group of variables that influences water consumption. Results of this research are sparse and not unequivocal. Ideological traits do influence water consumption [*Gilg and Barr*, 2006], but the effect of other factors, such as education or generational habits is not yet well understood [*Beal et al.*, 2010; *March et al.*, 2010].

2.2.2. Nonprice Water Conservation

Water conservation is pursued through a range of nonprice policies: mandatory regulations, such as building codes that require the installation of water efficient plumbing or restrictions of outdoor water practices; rebates for the purchase of water saving fixtures, information, and education campaigns [*Saurí*, 2013].

The assessment of nonprice conservation measures has become a major topic of research, but methods and focus of inquiry are not consistent. Table 1 details the finding of this group of studies. Many authors assess effectiveness of water conservation measures by adding them to more traditional water demand models; others are more experimental and monitor water usage before and after the installation of water conservation equipment, or compare users of water-conservation devices with control groups. Some focus on effectiveness and other on efficiency. Most target individual users and very rarely the organizations that implement them.

Results of empirical studies on the effectiveness of conservation strategies are not always unanimous or methodologically sound. There is a general agreement that most water saving technologies, although effective, produce less water savings than expected [*Campbell et al.*, 2004; *Lee*, 2011, *Mayer et al.*, 2009; *Mayer and DeOreo*, 1999; *Price et al.*, 2014; *Renwick and Archibald*, 1998; *Renwick and Green*, 2000; *Tsai et al.*, 2011]. Technical factors play a role. Reducing the capacity of toilet tanks, for example, has given the expected results consistently [*DeOreo et al.*, 2001, p. 64]. On the other end, weather-based irrigation systems, that have the potential to reduce water used for irrigation between 15% and 34% in a laboratory setting, in real settings curb water consumption only by 6.1% [*Mayer et al.*, 2009, p. xvii]. Whether it is efficient to subsidize the adoption of water efficient technologies is also not clear. Studies find that in the case of rebates to

Table 1. Nonprice Water Demand Management Measures and Their Effectiveness

Author and Year	Geographical Scope	Type of Measure	Correlation With Water Usage	Results of the Experiment
Campbell et al. [2004]	Phoenix (AZ)	Mandatory low flow fixtures	Negative	
		Outdoor watering restrictions	Positive	
		Free retrofit kits 1	Positive	
		Free retrofit kits 2	Positive	
		Free retrofit kits 3	Negative	
		Free low water seeds	Positive	
		Information	Positive	
		Neighborhoods initiatives 1	Negative	
		Neighborhoods initiatives 2	Negative	
Hanemann and Nauges [2005]	Los Angeles (CA)	Mandatory conservation	Negative	
		Voluntary conservation	Negative	
Hughes [2012]	California	Memorandum of understanding with 14 best management practices	Not significant	
Kenney et al. [2008]	Aurora (CO)	Indoor rebates	Negative	
		Outdoor rebates	Not significant	
		Smart meter	Positive	
Michelsen et al. [1999]	Los Angeles, San Diego, Denver, Albuquerque, San Francisco	Additional conservation measures	Negative	
Renwick and Archibald [1998]	City of Goleta and Santa Barbara	Outdoor watering restriction	Negative	
		Water budget	Negative	
		Traditional irrigation techniques	Positive	
		Water efficient irrigation techniques	Negative	
		Showerheads reductions adopted	Negative	
		Toilet reductions adopted	Negative	
Renwick and Green [2000]	Cities in California	Public Information Campaign	Negative	
		Ultra low flow toilets rebates	Not significant	
		Free retrofit kits	Negative	
		Water budgets	Negative	
		Outdoor watering restrictions	Negative	
Tsai et al. [2011]	Ipswitch (MA)	Weather sensitive irrigation devices		n.s.
		Water harvesting systems		Undetectable
		Indoor audit and retrofit		4.93 m3 per quarter
		Indoor rebates audit and retrofit		5.01 m3 per quarter
		Indoor rebates		5.15 m3 per quarter

reduce the cost of replacing existing fixtures with water saving equipment, only 33% of the water savings associated to the program were to ascribe to the subsidies and 67% of the households that took advantage of the rebates would have replaced the fixture even without them [*Bennear et al*., 2013].

Voluntary water conservation commitments result effective at individual household level [*Renwick and Green*, 2000], but do not result in perceptible per capita water savings at the aggregate level [*Hughes*, 2012]. Local ordinances that limit outdoor irrigation are instead very effective [*Hanemann and Nauges*, 2005; *Kenney et al*., 2008; *Renwick and Green*, 2000; *Renwick and Archibald*, 1998], even if implemented on a voluntary basis and especially if coupled with a rate increase.

2.2.3. Price and Nonprice Water Conservation Strategies

The efficiency of market tools in managing externalities and natural resources is the topic of theoretical [*Coase*, 1960; *Karp and Gaulding*, 1995; *Revesz and Stavins*, 2007] and empirical literature [*Ellerman and Montero*, 2007; *Freeman and Kolstad*, 2006; *Revesz and Stavins*, 2007; *Stavins*, 2008; *Tietenberg*, 2003; *Tietenberg and Lewis*, 2000].

In the water sector, a number of studies proves theoretically that charging water at efficient market price to reduce water usage is more efficient than command and control strategies [*Griffin*, 2006, *Mansur and Olmstead*, 2012; *Olmstead*, 2010; *Olmstead and Stavins*, 2009; *Timmins*, 2003] and a number of studies tests this assumption empirically by comparing water pricing versus outdoor watering restrictions [*Grafton and Ward*, 2008; *Hensher et al*., 2006; *Brennan et al*., 2007]. Advocates of pricing as a conservation tool claim that water agencies should increase water rates to capture deadweight losses and use the resources to improve water supply reliability [*Hughes et al*., 2009; *Sibly*, 2008]. A more nuanced approach, instead, argues that given different elasticities in different situations, pricing can hardly be used as a conservation strategy [*Saurí*, 2013].

Water rates in the United States have been increasing considerably, but water management agencies are usually reluctant to increase them as a conservation tool and are much more likely to mandate water usage restrictions or to distribute subsidies to reduce the cost of water saving devices [*Boyer et al*., 2014].

This study tests three additional hypotheses based on the eclectic literature on water demand management: an increase of water rates is correlated with reductions of per capita residential water usage (H3); higher per capita rebates distributed by water agencies to their customers to purchase water saving devices are correlated with per capita residential water usage reduction (H4); mandates to permanently reduce outdoor water usage are correlated with residential water usage reduction (H5).

3. Background: Water Management and Conservation in Southern California

California has a long history of laws, policies, and practices that promote water conservation. At first, the effort was merely voluntary, but with time and increasing pressure on water supply it has become a mandatory commitment. To deal with water shortages, drought, and demographic growth, water agencies have implemented a combination of mandates, pricing, and rebates and are a good testing ground for the effectiveness of water conservation strategies.

Southern California is home of about 20 million residents, 54% of California population, and has groundwater and surface water resources to respond to the demand of about half of them. The remaining water is imported from the Colorado River, Northern California, and the Eastern Sierra. A large water agency, the Metropolitan Water District (MWD), manages the water imported from the Colorado River and from Northern California (to respond to about 53% of the total demand on average between 2001 and 2010) and serves most of Southern California. The agency sells water to its members: 13 cities and 13 special districts. Twelve of these special districts are wholesalers; they sell drinking water to 147 retail agencies: 54 cities, 60 special districts, and 33 investors owned utilities (IOU) that distribute water to households and businesses.

Since the 1980s, MWD has been deploying voluntary conservation programs. Initially the agency funded outreach and information campaigns and gradually moved to more complex initiatives. Starting with rebates on low flow toilets in the 1990s, the district has widened its programs to include water audits, rebates on weather-based irrigation controllers, high-efficiency washers, turf replacement, and specific

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programs for industrial customers. Rebates are directed to retail customers in the MWD service area and are distributed directly by MWD to local households. Funding sources come from a water management fee that member agencies pay according to their water purchases and from grants from the California Department of Water Resources (DWR) and the U.S. Bureau of Reclamation. They amount to about 1% of the agency's yearly $2 billion budget.

To address growing uncertainty about future water supply, in the last few years, the state has also deployed policies to rationalize urban water use, making the conservation effort more stringent and mandatory.

In 2009, the Governor declared the state of emergency for drought and gave order to all local agencies to pursue water conservation with more determination [*Department of Water Resources (DWR) et al*., 2010]. At the same time, DWR reduced the amount of water delivered to Southern California from the Northern part of the state, and MWD decided to reduce its deliveries to its member agencies by 10%. As a consequence, in 2009 and 2010 many local water retailers voted ordinances that mandated permanent outdoor irrigation limitations and other measures to curtail water waste.

Later that year, still in a drought and facing the inconsistency of the voluntary conservation effort, the state legislature passed a mandate to reduce per capita water consumption by 20% by 2020 and secured the water agencies' commitment by requiring that they meet an interim target by 2015 to be eligible for state funding for water infrastructures. In 2010, the California Public Utilities Commission extended the mandate to IOUs.

4. Research Design and Measurements

This research studies the effects of this group of conservation measures on per capita water usage. The geographic area object of this analysis is the service area of MWD that includes parts of Ventura, Los Angeles, San Bernardino, Riverside, Orange, and San Diego counties. The choice of this area is supported by the suggestion that research on water resources should be based on the analysis of cases that are different, but are in similar physical, and economic circumstances, in order to isolate institutional effects from other contextual influences [*Blomquist et al*., 2004]. The units of analysis of this inquiry are retail water agencies and districts that purchase part of their water supply from the MWD (about 147 among cities and special districts). They are under similar socioeconomic circumstances, face the same water scarcity issues, but are institutionally diverse. Data availability limitations, however, have reduced the scope of the analysis to 56 water agencies located in Orange and San Diego County and in the Western part of San Bernardino County.

The dependent variable of the empirical analysis is the yearly percent change of per capita residential water consumption between 2006 and 2010. The analysis is limited to residential water usage for two reasons. Residential uses make up 68% of urban water usage in the region, and are relatively simple to standardize by the number of residents in the agencies' service area. Also, residential rates are generally homogeneous for every residential customer and can be estimated more accurately.

Water demand data are provided by the California Department of Water Resources (DWR) (unpublished, 2012), population data by the U.S. Census [*U.S. Census*, 2011], adjusted with the estimated produced by the California Department of Finance [*Department of Finance* (*DOF*), 2012] and with data included in water agencies' Urban Water Management Plans (UWMP).

Based on the existing literature, this research tests five hypotheses.

1. H1: Water retailers with higher dependency on groundwater are less effective in reducing per capita water usage.

   This hypothesis supports the literature on natural resources management [*Anderies and Janssen*, 2013, *Ostrom*, 2005, 2009, 2010; *Wiek and Larson*, 2012; *Young*, 2002, 2010] that includes resource systems as essential elements for the analysis of complex socioecological systems.

2. H2: Size matters, large retailers are more effective than small agencies in reducing residential water usage.

   This hypothesis supports the claim that there are economies of scale in water management systems and that larger agencies perform complex water management tasks better than small agencies [*Heikkila*, 2004; *Saleth and Dinar*, 2004, 2005; *Schlüter and Pahl-Wostl*, 2007].

Hypotheses 3, 4, and 5 draw from the water demand management literature that claims that water demand is affected by prices [*Arbués et al*., 2003; *Dalhuisen et al*., 2003; *Duke et al*., 2002; *Grafton et al*., 2011; *Hewitt and Hanemann*, 1995; *Hoffman et al*., 2006; *Mansur and Olmstead*, 2012; *Olmstead et al*., 2007; *Worthington and Hoffman*, 2008], but also that mandatory water restrictions achieve relevant water reductions, but rebates for water saving devices are not always effective [*Campbell et al*., 2004; *Kenney et al*., 2004; *Renwick and Green*, 2000; *Renwick and Archibald*, 1998].

3. H3: Changes in water rates are negatively correlated with changes in per capita residential water usage.
4. H4: Per capita rebates distributed by water agencies to their customers to purchase water saving devices are negatively correlated with changes in per capita water usage.
5. H5: Mandates to permanently reduce outdoor water usage are positively correlated with water usage reduction.

Independent variables are the following (see Appendix A for sources of data): (a) percentage of total water demand supplied by groundwater in 2006 through 2010; (b) population served, a measure of the size of each water retail agency; (c) yearly percentage change in water rates between 2006 and 2010; (d) dollar amount of rebates for residential customers to purchase High Efficiency Washers (HEW), High Efficiency Toilets (HET), Weather Based Irrigation Controllers (WBIC), rotating nozzles and synthetic turf in 2006, 2007, 2008, 2009, and 2010 weighted on the number of residents of each retailer.

Control variables are: (a) yearly percentage change in precipitation for the timeframe between 2006 and 2010; (c) yearly percentage change in real per capita GDP for the timeframe between 2006 and 2010.

The model tested in the following sections can be summarized as follows:

$$\mathrm{Y_{it}} = \beta + \beta \mathrm{G_{it}} - \beta \mathrm{LnP_{it}} - \beta \mathrm{R_{it}} - \beta \mathrm{PCR_{it}} - \beta \mathrm{Pr_{it}} + \beta \mathrm{GDP_{it}} + \varepsilon_{\mathrm{it}} + \mathrm{u_{it}}$$

Where:

Y_{it} is yearly percentage change in per capita residential water consumption in each water retail agency;

G_{it} is percentage of water supply from groundwater in each water retail agency. The expectation is a positive sign, because water agencies that depend more on groundwater will be less interested in water usage reduction strategies for two reasons: First, they are less dependent on imported water, hence their water supply is less expensive, and they are not as exposed to MWD's rates increases as agencies that depend on imported water for a large percent of their supply. Therefore, they do not have the incentive to lower their costs. Second, if they do not use the groundwater for which they have appropriative rights they lose it. As a consequence, larger percentage of water supplied from groundwater is expected to correlate with smaller change in per capita water usage;

LnP_{it} is natural logarithm of resident population. The expectation is a negative sign, because water agencies with a larger customer base and more revenues have more resources and dedicated staff and are assumed to be more effective in implementing conservation strategies;

R_{it} is early percentage change in average residential water rates. The expectation is a negative sign to signify that by increasing water rates, per capita water usage will decline;

PCR_{it} is per capita rebates for water saving devices. The expectation is a negative sign, to signify that when agencies have more resources for rebates, water usage declines faster;

ORD_{it} is ordinances to reduce outdoor water usage. The expectation is a negative sign. When the ordinance is in place, residential water usage is expected to decline;

Pr_{it} is yearly percentage change in precipitation. The expected sign is negative, because in rainier years households use less water for outdoor irrigation;

GDP_{it} is yearly percentage change in per capita local GDP. The expected sign is positive, because when wealth increases families are not inclined to save on water usage, while in times of recession all types of consumption are more likely to decline.

The sample includes data for 56 different water agencies for 5 consecutive years for an *n* of 280 observations.

Table 2. Comparison of Sample and Population[a]

Item	Sample	Population
Average percentage groundwater supply 2005–2010	36.5%	44.4%
Average number of residents in 2007	120,116	158,267
Average total water demand in 2010 (AFY)	20,593	20,609
Percentage residential water demand in 2010	68.4%	69.7%
Average per-capita water usage in 2008 (gpcpd)	224	198
Average yearly precipitations 2005 - 2010 (inches)	12.9	15.5
Percentage of cities	44.8%	45.0%
N	56	145

[a]Source: Water retailers' UWMPs.

The analysis uses a panel data regression with fixed effects.

The process for defining the appropriate statistical method includes five stages. At first, bivariate analysis and a correlation matrix revealed low correlation coefficients among the variables. As second step, the data were analyzed with pooled OLS and tested for multicollinearity and heteroskedasticity. Although the Variance Inflation Factor (VIF) test presented very limited collinearity bias, the Breusch-Pagan/Cook-Weisberg test highlighted significant heteroskedasticity. The Breush and Pagan Lagrange multiplier test for random effects and a Hausman test for fixed effect suggested that a robust panel regression with fixed effects was the appropriate statistical method.

As a statistical procedure, panel regression with fixed effects has numerous advantages that compensate for the lack of information typical of water demand research. It allows us to take into account the diversity of individual cases and controls for variables that cannot be observed but recur regularly across cases [*Baltagi*, 2008, p. 6].

A comparison between the sample and the entire population of the region is summarized in Table 2.

Although the sample has been selected based on data availability and not randomly, it represents the entire population fairly well. The sample water agencies are very similar to the total population: they are slightly smaller, slightly drier and depend on imported water slightly more, but their governance structure (less than 50% are cities) and the percentage of residential water demand on total water demand matches the entire population.

5. Results and Discussion

Summary statistics provided in Table 3 describe the nature of the sample, the characteristics of the conservation effort and the extreme variability included in the sample.

The results from the panel regression with fixed effect are presented in Table 4 and show that contextual factors such as changes in precipitations and changes in the local economic output are strongly correlated with changes in per capita residential water usage. They show also that only mandates to curb outdoor irrigation are significantly correlated to changes in water consumption and that nor rebates or changes in water rates have significant correlation to residential water customers' behaviors. They finally show that size of water agencies is significantly correlated to changes in per capita water usage. The results are confirmed by the model without outliers, small and very large water agencies that could potentially bias the coefficients.

Table 3. Summary Statistics

Variable	Mean	Std. Dev.	Min	Max	Obs.
Per-capita residential water usage: yearly % change	−3.1%	0.075	−20.2%	17.6%	280
Resident population	120,116	170,363	3,584	1,245,929	280
Water supply: % of groundwater	36.5%	0.313	0.0%	100.0%	280
Residential rates: yearly % change	8.6%	0.067	−13.0%	45.2%	280
Per-capita $ amount of rebates for water saving devices	0.91	0.94	0.00	7.33	280
Local watering restriction ordinances = 1	0.36	0.48	0	1	280
Precipitations: yearly % change	38.3%	1.027	−62.9%	251.2%	280
Real per-capita GDP: yearly % change	−1.1%	0.032	−8.64%	4.27%	280

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Table 4. Estimates of the Panel Data[a]

Variable	Robust Fixed Effect Coefficients: Entire Panel	Robust Fixed Effect Coefficients: Panel Without Outliers
Natural log of resident population	−0.998***	−0.956***
	(−3.35)	(−3.23)
Water supply: % of groundwater	0.029	0.025
	(0.71)	(0.58)
Yearly % change of residential water rates	−0.069	−0.050
	(−1.22)	(−0.80)
Per-capita $ amount of rebates for residential water saving devices	0.005	0.005
	(0.74)	(0.72)
Local water restriction ordinances	−0.015*	−0.017**
	(−1.79)	(−2.01)
Precipitations: yearly % change	−0.024***	−0.024***
	(−5.11)	(−4.85)
Per capita GDP: yearly % change	0.752***	0.732***
	(5.70)	(5.48)
Constant	11.133***	10.667***
	(3.35)	(3.22)
Within R^2	0.4836	0.4810
$p > F$ (7, 55)	0.000	0.000
N	280	270

[a] $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$ (t-values in parentheses).

This research examines policy and contextual factors that are correlated with water retail agencies' ability to reduce daily per capita water usage. The study focuses on the 2006–2010 time frame and captures a very crucial moment of Southern California water conservation history, characterized by a very severe dry spell, a drought emergency gubernatorial declaration and restrictions of imported water deliveries [*DWR et al.*, 2010]. For lack of comprehensive data, it captures the behavior of a group of agencies that are slightly different from the average Southern California water agency, but also have some similarities.

The first consideration is about the model's specification. This research is different from most research on water demand. Most research in this field models individual households' demand and focuses on households' characteristics and prices to understand the relationship between prices and demand [*Arbués et al.*, 2003; *Dalhuisen et al.*, 2003; *Duke et al.*, 2002; *Grafton et al.*, 2011; *Hewitt and Hanemann*, 1995; *Hoffman*, 2006; *Mansur and Olmstead*, 2012; *Olmstead et al.*, 2007; *Worthington and Hoffman*, 2008]. Research that takes into effect other forms of water demand management is limited, equally focused on the individual household and usually models demand management measures as a dummy variable. The strength of previous research is the large number of cases, the use of many independent variables that define the households' characteristics [*Campbell et al.*, 2004], and of numerous attributes that control for the seasonality of water consumption [*Renwick and Green*, 2000; *Renwick and Archibald*, 1998]. Its weakness is that it does not analyze the overall result of a policy action and it obviously does not take into account the characteristics of the implementing agencies. The strength of the specification proposed in this analysis is that it analyzes the outcome of policy actions implemented by water agencies and measures the amount of resources that water organizations make available for water customers to purchase water saving devices, a variable that, due to data limitations, has not been used before. Its weakness is a small number of cases, a short panel, and the lack of potentially significant variables such as the rate of market penetration of water efficient appliances, changes in land use characteristics, and changes in consumers' attitudes.

The choice of a fixed effects panel regression with robust standard error has been guided by a number of statistical tests and is appropriate to the available data. The concern that outliers could bias the results of a short panel with a limited number of cases has been addressed by comparing the results of the entire panel with the results of the panel without outliers. The concern, however, remains that a 5 year panel with 56 different cases might have limited significance. Future research needs to address this limitation.

Two hypotheses, formulated through the review of the current literature on institutions and water management, focus on institutional and structural characteristics of the water agencies. The first is not supported by the empirical analysis, while the second is supported.

1. *H1: water retailers with higher endowment of ground water are less effective in reducing per capita water is not supported.*

   Although the sign of the coefficient is positive as expected, the statistical analysis does not confirm the proposition drawn from the natural resources management literature [*Anderies and Janssen*, 2013; *Ostrom*, 2005, 2009, 2010; *Wiek and Larson*, 2012; *Young*, 2002, 2010].

2. *H2: size matters, large retailers are more effective in reducing residential water usage than smaller retailers, is supported*.

The findings confirm the literature on fragmentation [*Heikkila*, 2004; *Pahl-Wostl and Knieper,* 2014; *Saleth and Dinar*, 2004; *Schlüter and Pahl-Wostl*, 2007] that points out that up to certain size water agencies are more efficient in providing their services and water conservation managers confirm that smaller water agencies lack the resources to implement conservation strategies consistently. The reduction in daily per capita residential water use correlated with the agencies' size, however, is very small. By almost tripling the number of residents, per capita water usage decline would increase by 1%.

Three hypotheses formulated through the review of the current literature on water demand management address the effectiveness of water conservation strategies and offer mixed results.

3. *H3: An increase in water rates is correlated with a reduction of daily per capita residential water usage is not supported*.

The lack of significance of the correlation of changes in pricing to changes in per capita water consumption is not consistent with the existing literature [*Arbués et al*., 2003; *Dalhuisen et al*., 2003; *Duke et al*., 2002; *Hewitt and Hanemann*, 1995; *Hoffman et al*., 2006; *Olmstead et al*., 2007; *Worthington and Hoffman*, 2008], where water rates have a consistently statistically significant, although small, negative correlation with water demand. The sign of the coefficient, however, is negative as predicted and consistent with the existing literature. One explanation for this discrepancy is that in Southern California water agencies do not use rates as a water conservation tool and often raise rates after water consumption has declined, to compensate for loss of revenues. An alternative explanation is that rates have grown very quickly in the last two years and their correlation with changes in water related behaviors needs to be measured on a longer time span.

4. *H4: Higher per capita rebates distributed by water agencies to their customers to purchase water saving devices are correlated with higher water usage reduction, is not supported*.

The results confirm the claim [*Kenney et al*., 2008] that rebates on outdoor water saving devices do not have a statistically significant correlation with changes in water usage. Rebates, per se, are a very small component of the conservation effort. The amount of resources water agencies deploy is not sufficient to have any influence on local water consumption and in some cases rebates are directed to ineffective fixtures. Also, even when households that have access to rebates actually reduce their water demand, neighboring households could increase their water consumption, offsetting the effects of the rebates.

5. *H5: Changes in per capita water usage are correlated with the approval of local ordinances limiting outdoor watering and water waste is supported*.

The results of the empirical test confirm the conclusions of most research on nonprice water conservation and the finding that outdoor water usage restrictions are effective in reducing water usage [*Hanemann and Nauges*, 2005; *Renwick and Green*, 2000; *Renwick and Archibald*, 1998]. The problem with strong mandates issued in a crisis, however, is whether they can yield consistent results in the long term.

6. Conclusions

As we move into a future where droughts are projected to be more frequent and intense, it is reasonable to assume that demand side policies will become ever more strategic for water agencies. This research, however, indicates that the implementation of some of these strategies is not always successful and that water management agencies need to envision more effective demand management policies.

Some results confirm previous findings. Economic development, environmental settings, and institutional factors affect water agencies' performance [*Saleth and Dinar*, 2004]. These considerations are valid for all water management systems and can be applied to water conservation, as changes in weather, wealth, and rules have a significant effect on the outcomes of water demand management policies.

Among the three policy options considered in this research, mandates to curb outdoors water usages, rebates for water efficient equipment and rates, the statistical analysis finds that only mandates have a significant correlation with residential water usage. The amount of rebates for water efficient equipment and pricing are not influential. This partially confirms what seen previously about water mandates, [*Hanemann and Nauges*, 2005; *Renwick and Archibald*; 1998; *Renwick and Green*, 2000] but contradicts those who found that rebates for water saving devices are effective [*Renwick and Archibald*, 1998; *Campbell et al*., 2004] and that water demand's price elasticity, although small, is mostly significant [*Arbués et al*., 2003; *Dalhuisen et al*., 2003; *Olmstead et al*., 2007; *Worthington and Hoffman*, 2008]. Research on water saving technologies [*Mayer et al*., 2009] suggests that rebates are not effective because they sometime support low yield technologies. Interviews with water managers explain that water rates are not effective as expected because water agencies are reluctant to increase water rates for political reasons and they often do so only when revenues start declining. Moreover, California constitution mandates water agencies to price water only to recover construction and maintenance costs and does not encourage for conservation pricing.

Among the variables that describe the institutional characteristics of the water agencies, the analysis finds statistically significant negative correlation between the size of the organization and changes in per capita water use. A larger customer base is correlated with larger reductions in per capita water usage. This finding mirrors previous research on the adoption of conjunctive management practices [*Heikkila*, 2004] and other authors' conclusions that a certain degree of centralization has a positive correlation with the performance of water management systems [*Saleth and Dinar*, 2004, 2005; *Schlüter and Pahl-Wostl*, 2007]. Water conservation managers confirm that larger water agencies are generally more proactive in implementing water conservation measures. They also have more resources to invest in water conservation and to deploy information about rebates opportunities or water ordinances.

Although the external validity of the results of a short panel with a limited number of cases is not very strong, existing literature and in depth interviews with local water managers support some of the findings. Additional research is needed to explore whether different form of governance and interagency collaboration influence agencies' performance. Additional research is also needed to clarify how water agencies make decisions about pricing and which pricing methods are more effective in controlling water usage without burdening lower income households.

In a policy perspective, the transition from a water supply to a water demand management-oriented strategy appears guided by contextual factors such as the economic cycle and the weather, which occur outside the water governance system, and by strong mandates rather than by market-based water management strategies.

Four policy suggestions to water agencies to hasten the transition from supply to demand side management emerge quite clearly. Count on extensive mandates to curb water consumption until water thrifty behaviors become undisputed. Improve pricing strategies by adopting more sophisticated pricing structures. Support only very effective water efficient fixtures and invest resources only where substantial water savings are expected. Support agencies with a small customer basis that are less effective in leading their customers in changing their water habits or encourage inter agencies' agreements to manage water conservation strategies, and provide assistance for agencies' consolidation.

Appendix A

1. Yearly percentage change in per capita residential water usage between 2006 and 2010. Sources of data: California Department of Water Resources (DWR) (unpublished, 2012), *Public Water System Statistics 2006–2010*, Excel data set provided by DWR; *DOF, 2012*, and *U.S. Census*, 2011. Variable name is *PERCAPITA*.

2. Percentage of total water demand supplied by groundwater in 2006 through 2010. Sources of data are: Inland Empire Utilities Agency (IEUA) (unpublished, 2012a), *IEUA Annual Water Supply Report*, Excel table provided by IEUA; Municipal Water District of Orange County (MWDOC) (unpublished, 2012a), *OC Water Consumption Info_5.22.12*, Excel table provided by MWDOC; San Diego County Water Authority (SDCWA) (unpublished, 2012a), *SDCWA 1999–2011 water supply*, Excel table provided by SDWCA. Variable name is *SUPPLYGROUND.*

3. Population served, a measure of the size of each water retail agency. [*DOF*, 2012; *U.S. Census*, 2011]. Variable name is *POPLOG*.

4. Yearly percentage change in water rates between 2005 and 2010. Sources of data: American Water Works Association, and Raftelis Inc. (unpublished, 2013a), CA-NV 2005 Water Rate Survey, edited by American Water Works Association, Rancho Cucamonga CA, American Water Works Association, and Raftelis Inc.

(unpublished, 2013b), CA-NV 2007 Water Rate Survey, edited by American Water Works Association, Rancho Cucamonga CA; American Water Works Association, and Raftelis Inc. (unpublished, 2013c), CA-NV 2009 Water Rate Survey, edited by American Water Works Association, Rancho Cucamonga CA.; Orange County Water Agencies, Orange County Water Association, and Municipal Water District of Orange County (unpublished, 2005 through 2010), Water Rate$ Water System Operations and Financial Information, available at http://www.mwdoc.com/services/reports-studies; water agencies, personal communications (2013); Variable name is *RATENEW*.

5. Amount of rebates for residential customers to purchase High Efficiency Washers (HEW), High Efficiency Toilets (HET), Weather Based Irrigation Controllers (WBIC), rotating nozzles and to replace natural turf with synthetic turf in 2006, 2007, 2008, 2009, and 2010, weighted on the number of residents of each retailer. Sources of data are IEUA (unpublished, 2012c) Annual Water Use Efficiency Programs Report FY 2010/2011, available at http://www.ieua.org/news_reports/docs/2011/FY2010-_11_IEUARegionalWaterUseEfficiencyProgramsAnnualReport.pdf; MWDOC (unpublished, 2012c), Orange County Water Use Efficiency Programs Savings and Implementation Report, Adobe Acrobat file provided by MWDOC; SDCWA, SDCWA 1999–2012 data request, Excel table provided by SDWCA (unpublished, 2013).Variable name is *PCREBATE*.

6. Local ordinances have been modeled with a dummy variable with value 1 for every agency that put in place a water usage restriction ordinance from 2006 through 2010. Ordinances adopted during the first semester were attributed to the year of approval; ordinances adopted from July on were attributed to the following year. Sources of data: water agencies' internal documents. Name of the variable is *ORDI*.

Control variables:

1. Yearly percentage change in precipitation for the timeframe between 2006 and 2010. [*PRISM* 2006, 2007, 2008, 2009, 2010, 2011]. Variable name is *PREC*.

2. Per capita real GDP rate of change between 2006 and 2010 in San Bernardino—Riverside Metropolitan Statistical Area (MSA) defines changes in economic output for water retail agencies in San Bernardino County, changes in GDP in Los Angeles, Long Beach, and Santa Ana MSA represent changes in Orange County water retail agencies' economic output and changes in San Diego MSA represent changes in San Diego County water retailers [*Bureau of Economic Analysis*, 2013]. Name of the variable is *GDP00*.

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